

POPULAR SCIENCE

INCLUDING **MECHANICS** AND HANDICRAFT

35c March

Cars: What You Save on a Six PAGE 75
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100-Knot Liner to Fly on Sea Wings

PAGE 106

POPULAR SCIENCE

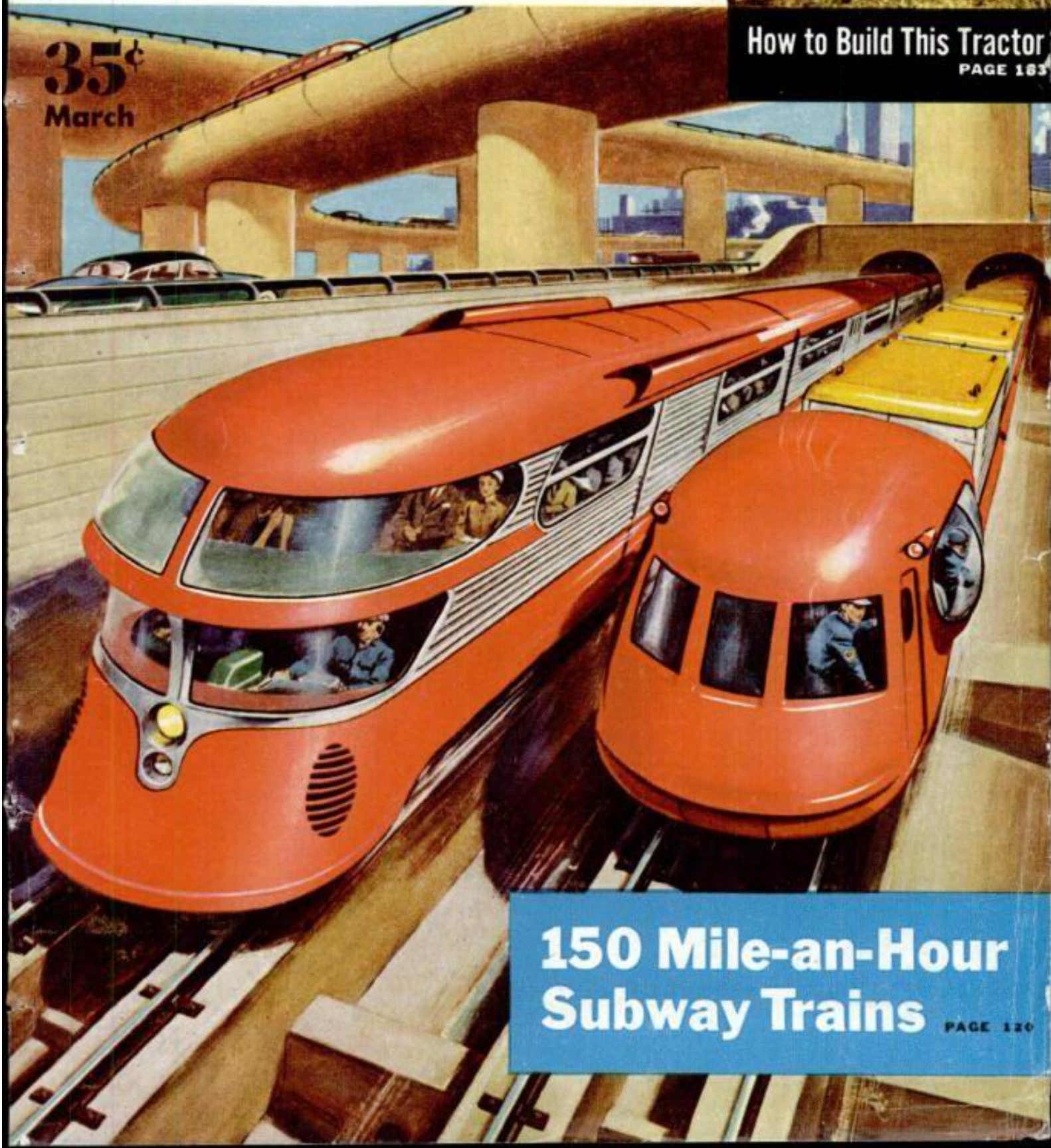
MONTHLY

MECHANICS - AUTOS - HOMEBUILDING

35¢
March



How to Build This Tractor
PAGE 183



150 Mile-an-Hour
Subway Trains

PAGE 120

It would cost hundreds of millions, but wouldn't it be nice to commute on a rubber-cushioned roadbed?

By Henry B. Comstock

EVERY commuter has a dream. In it, he enjoys a leisurely breakfast, strolls to the station, sinks into the padded seat of a streamliner and—*whoosh*, he's off on a 10-minute run to the city.

Now a rapid-transit expert claims that money, planning, new trains and new tracks could make the dream come true. The same techniques, he says, could give back to the railroads a lot of lost passenger traffic.

The man with the plan is John A. Hastings, a former New York state senator. He bases it on a new roadbed and an improved car truck. He holds patents on both.

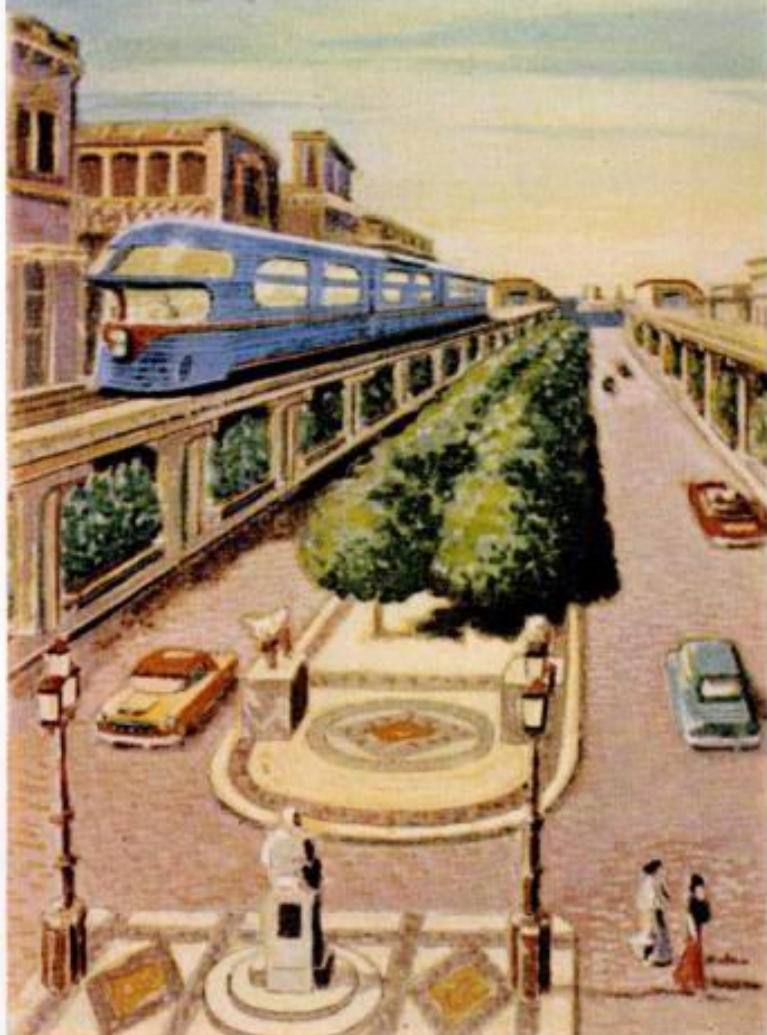
The roadbed would be prestressed concrete—either prefabricated or cast at the site. In cities, this roadbed would be laid underground; in suburban areas



KEY to 2½-mile-a-minute speeds and low maintenance costs, says Hastings, is a prefab, prestressed concrete roadway, with rails mounted on resilient rubber insets.

120 POPULAR SCIENCE

Catching



Havana is interested in John Hastings' new

the horizontal beams that hold the rails would be carried on vertical piers.

Hastings says his scheme would cost no more than building ordinary subways and railroads, and would result in:

- Cheaper maintenance, since there would be no ballast or tie replacement,

the 8:05 Could Be a Thrill



high-speed transit plan and its by-product: welcome shade for Cuban window-shoppers.

and regrading costs are eliminated.

- Faster trains, since the stability of the fixed roadbed would minimize train sway and bumps.

Hastings' improved car truck is adapted from one developed to give street cars a smooth ride and quick accelera-

tion. He has added rubber mountings to increase resistance to side sway and vibration. Each truck mounts an electric motor, to be powered either by a third-rail or a diesel-driven generator in the locomotive. Hastings plans to use the trucks on lightweight, low-hung trains,

TOOLED OUT of bedrock 100 feet below mid-Manhattan, New Jersey and Long Island streets, eight subway stations would each be served by 28 high-speed passenger elevators—enough to whisk 20,000 commuters an hour to and from their coaches on the 8:05. Freight containers would descend on eight still-larger lifts from motor vans on street to flatcars below.

teamed with his precast roadbed. He predicts speeds of 100 to 150 m.p.h.

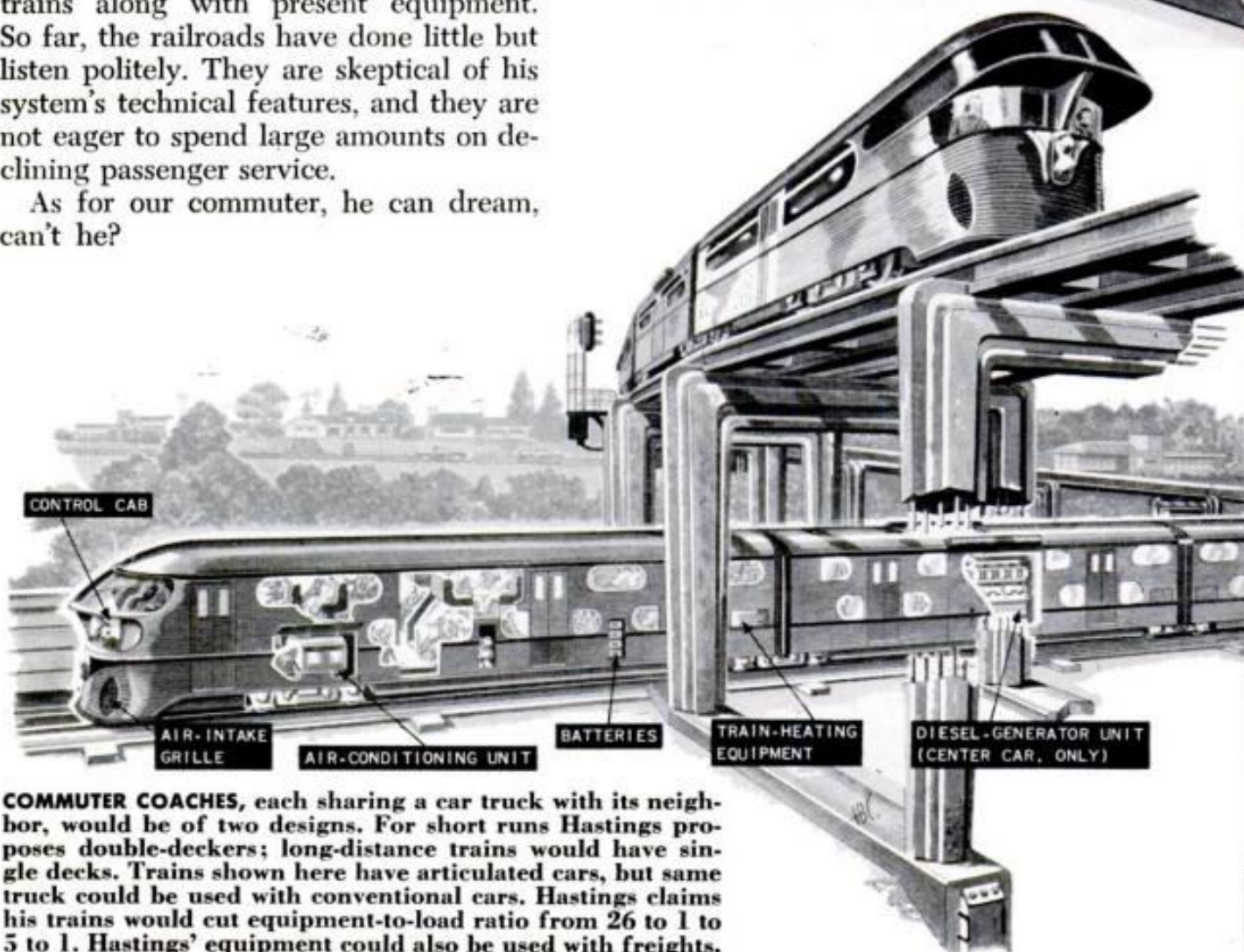
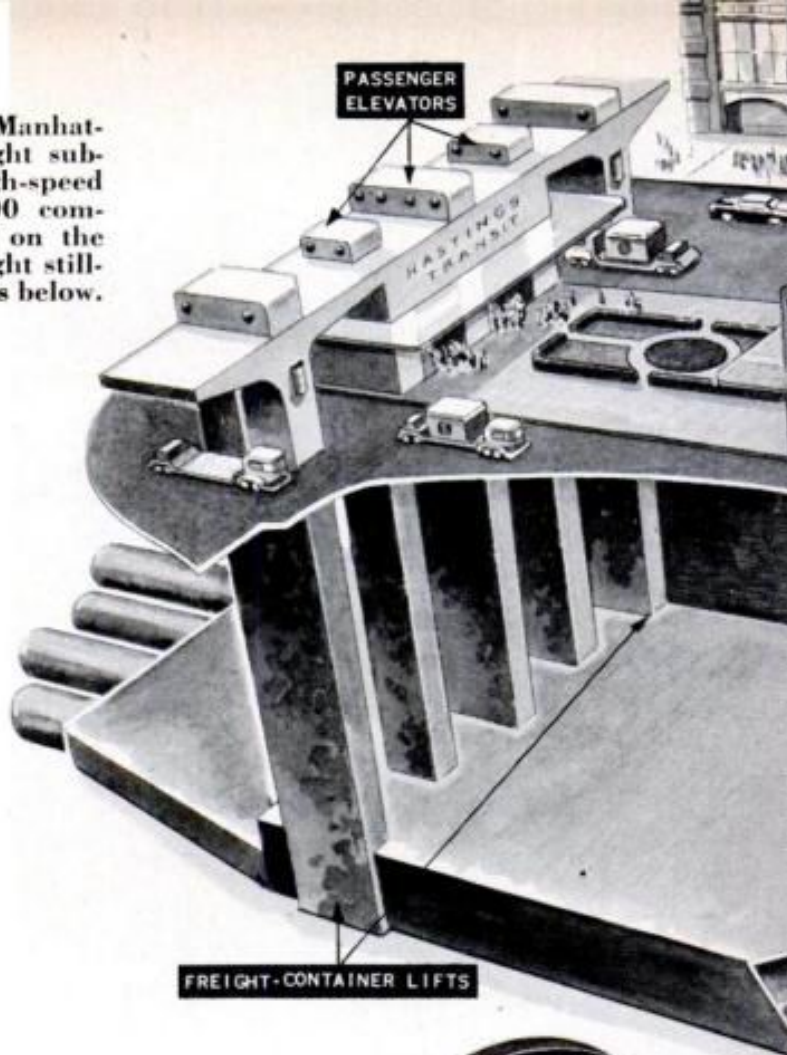
On a Hastings train you would pay your fare by the zone—like parcel post. He figures the cost at 15 cents for the first 15-mile zone, up to 50 cents for the 50-mile zone.

Cost: \$900,000,000

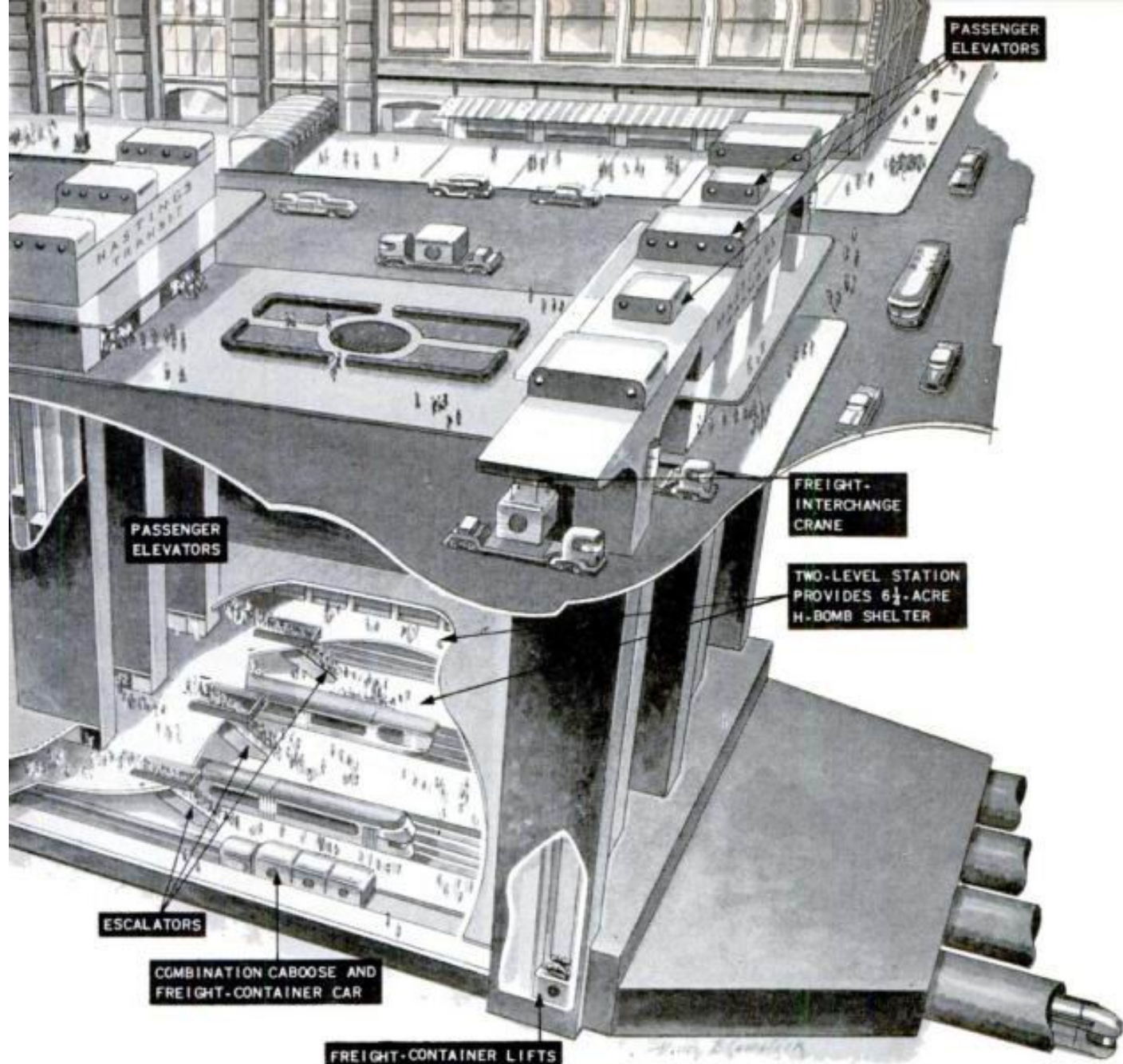
Both train and track would be used in a Hastings plan to rush commuters into New York. Involving purchase of the Long Island Rail Road and new four-track tunnels from New Jersey to Long Island, this would cost \$900,000,000.

Meanwhile, Hastings points out that any railroad could use his track and trains along with present equipment. So far, the railroads have done little but listen politely. They are skeptical of his system's technical features, and they are not eager to spend large amounts on declining passenger service.

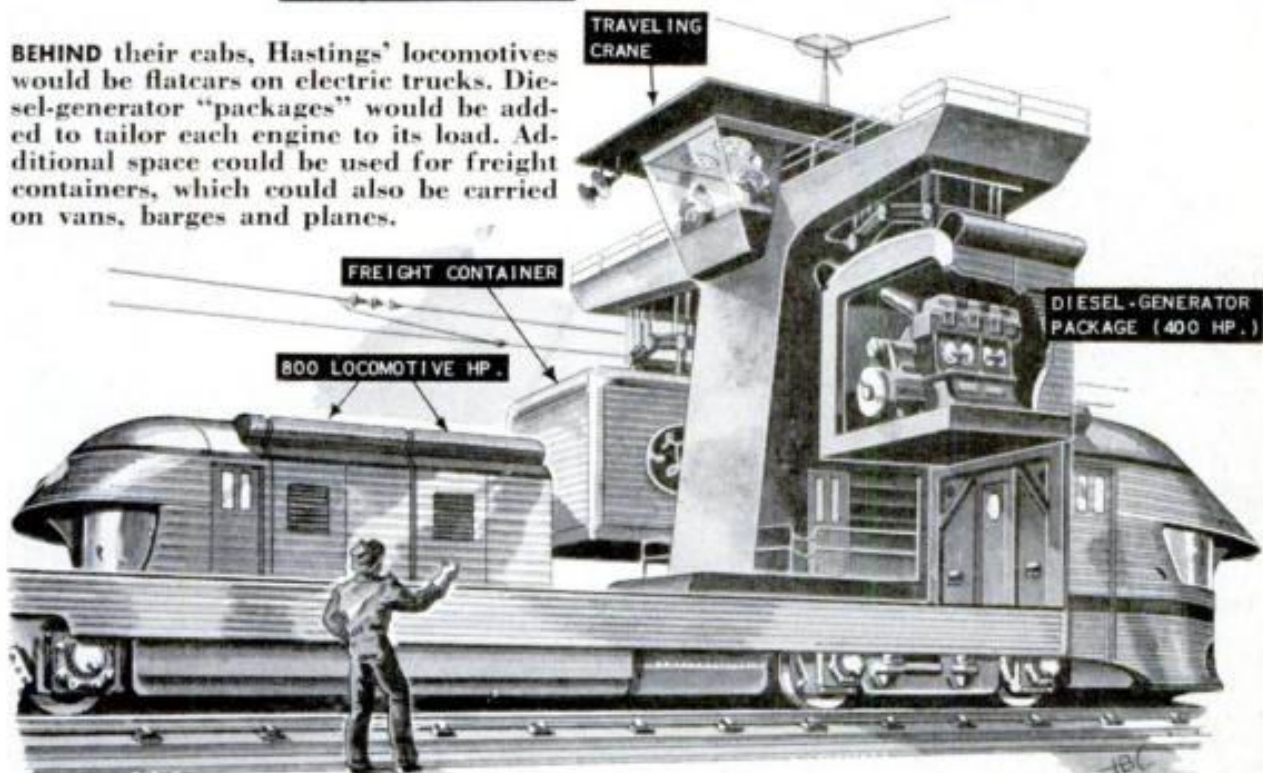
As for our commuter, he can dream, can't he?



COMMUTER COACHES, each sharing a car truck with its neighbor, would be of two designs. For short runs Hastings proposes double-deckers; long-distance trains would have single decks. Trains shown here have articulated cars, but same truck could be used with conventional cars. Hastings claims his trains would cut equipment-to-load ratio from 26 to 1 to 5 to 1. Hastings' equipment could also be used with freights.



BEHIND their cabs, Hastings' locomotives would be flatcars on electric trucks. Diesel-generator "packages" would be added to tailor each engine to its load. Additional space could be used for freight containers, which could also be carried on vans, barges and planes.



100-Knot Liner

to Fly on Sea Wings

An ultra-fast new way to travel, in vessels that ride high above the waves, is promised by the conquest of the sea's speed limit

By Alden P. Armagnac

DRAWINGS BY BOB McCALL

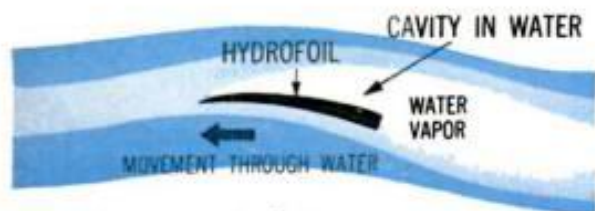
YOU'LL skim to Europe at mile-a-minute speed or more, in liners that ride above the waves on stilt-like legs and underwater wings. Coastal liners, of similar submerged-wing or hydrofoil type, will whisk you to vacation climes at a fantastic 100 knots, or 115 land miles an hour. An American breakthrough in marine science makes it feasible to build such ships as these. The long-standing speed limit for seagoing vessels is shattered by a revolutionary new "supercavitating" shape for hydrofoils and water propellers.

Whether this discovery can be exploited in ultra-fast passenger liners is answered with a "yes" by a six-month,

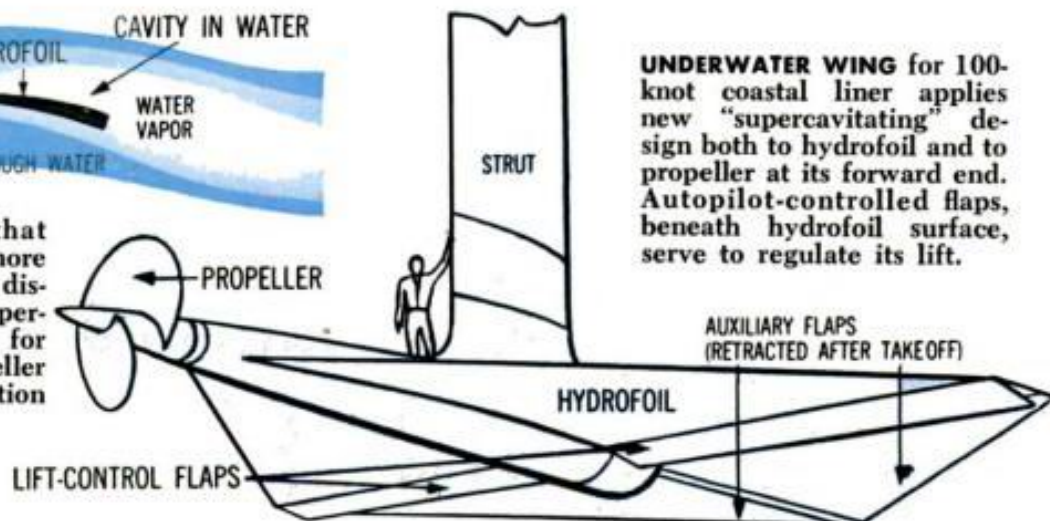
\$75,000 engineering study recently completed for the U.S. Maritime Administration by the Grumman Aircraft Engineering Corporation, Bethpage, N. Y. What some of the resulting ships will look like may be seen in the pictures that follow, based on actual drawings in the Grumman study's three-volume report.

Already under way is the next step to make these dreamboats come true. The Maritime Administration has just commissioned Grumman to design an 80-knot, 100-passenger hydrofoil ship as a prototype. Expected to be launched and cruising by late 1960, this experimental-scale vessel of 70 tons and 110-foot length will be powered by gas turbines totaling 10,000 hp. or more, which will propel the radical craft by driving water pro-

[Continued on page 238]



BREAKTHROUGH that conquers barrier to more speed for ships is discovery of the "supercavitating" profile, for hydrofoils and propeller blades, shown in action in diagram above.



UNDERWATER WING for 100-knot coastal liner applies new "supercavitating" design both to hydrofoil and to propeller at its forward end. Autopilot-controlled flaps, beneath hydrofoil surface, serve to regulate its lift.

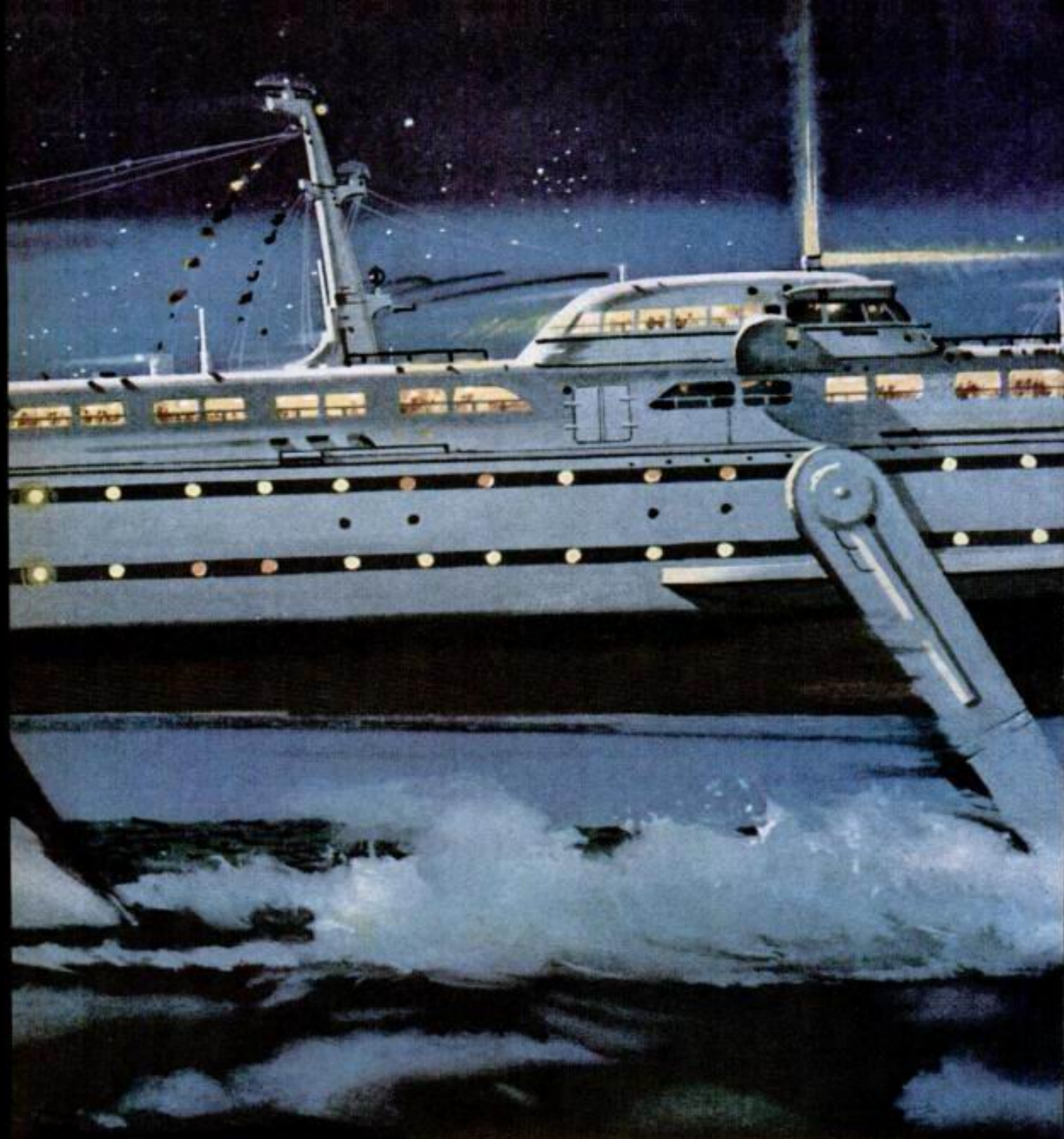
Unfold to See Atomic Ship at Full Speed ▶



Taxiing



Liner departs with foils retracted, hull submerged, using a non-atomic auxiliary engine.



Taking Off



In open water, foils go down, A-engine starts, and hull rises from water as vessel gains speed.



Yachtlike 320-passenger vessel of 1,000 tons, propelled on "wings" by A-power, will race across Atlantic twice as fast as today's sea queens. Unlimited in range, this hydrofoil liner will speed at 65 knots, or 75 m.p.h. Others of shorter range will be even faster.

Cruising

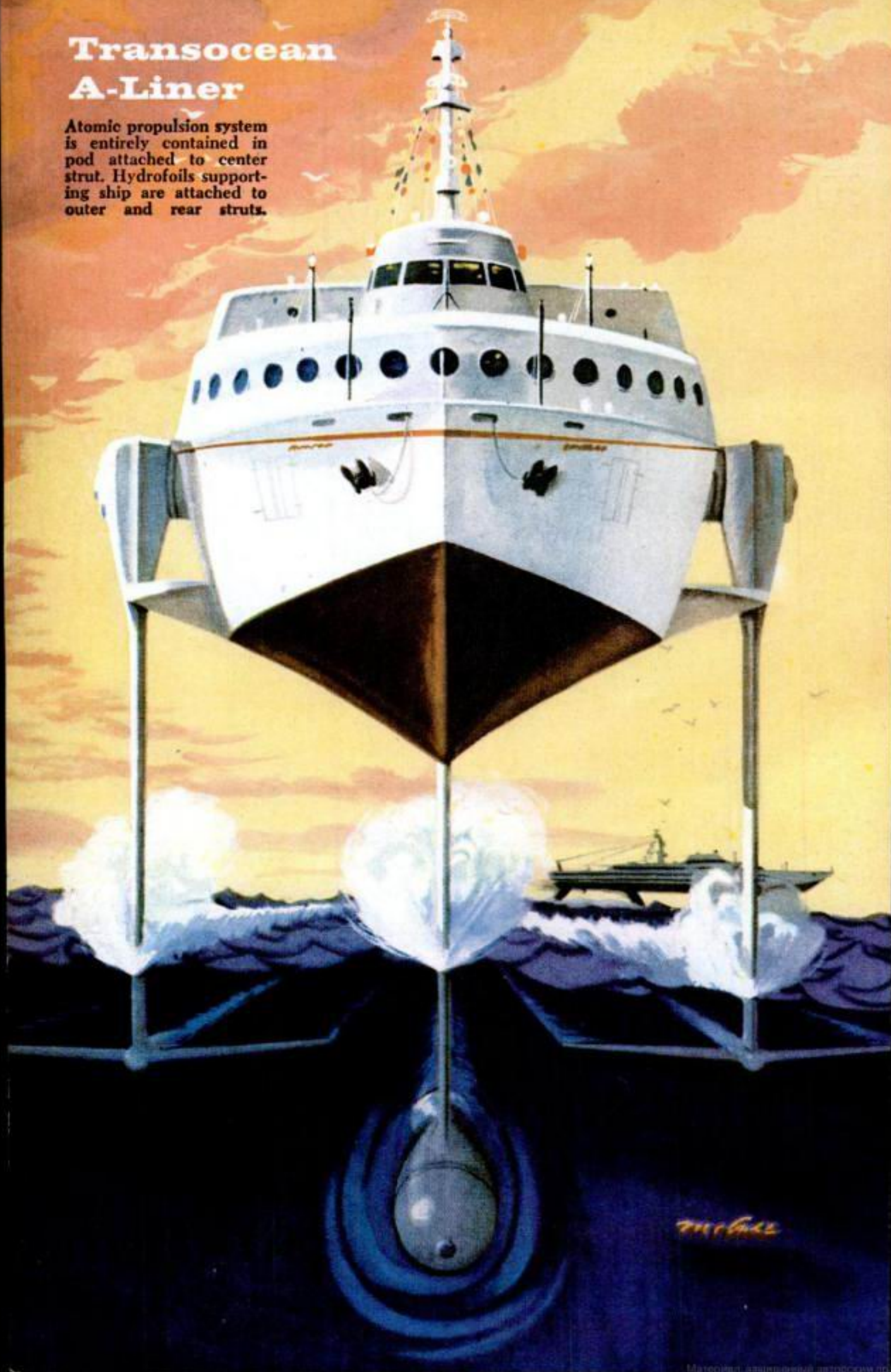


At full speed, hull rides high above waves. Reversing these maneuvers concludes voyage.

McLan

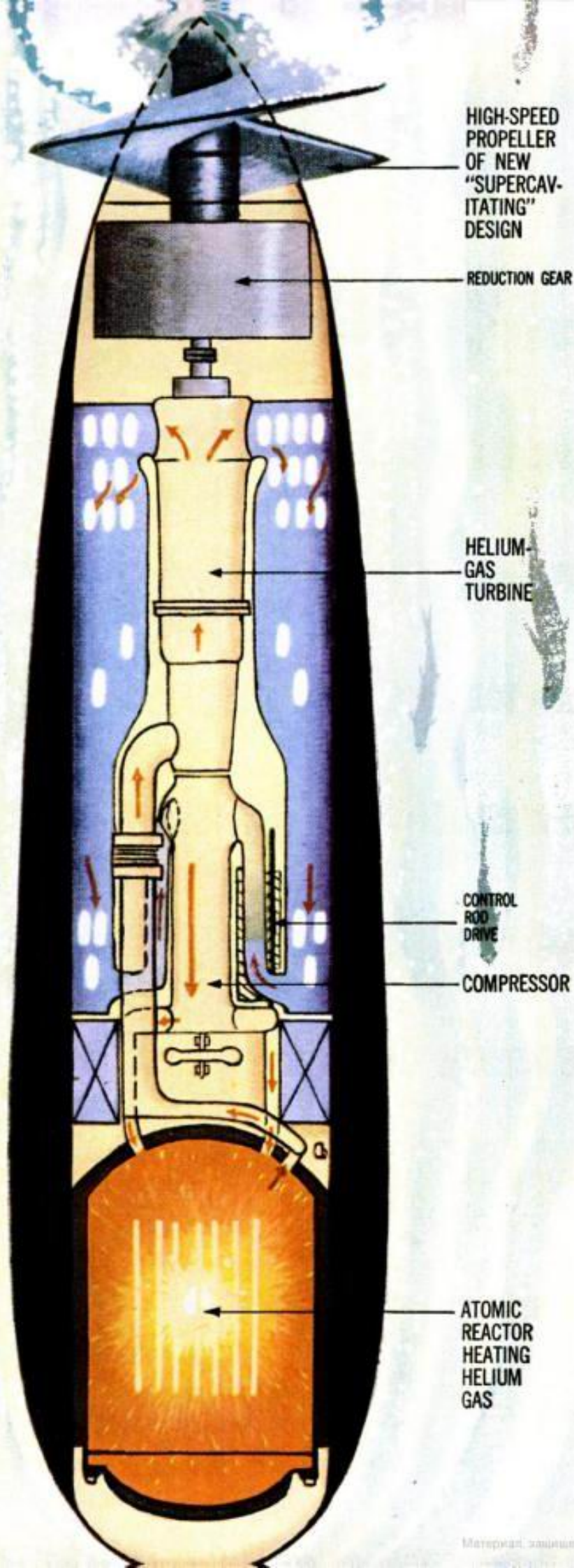
Transocean A-Liner

Atomic propulsion system is entirely contained in pod attached to center strut. Hydrofoils supporting ship are attached to outer and rear struts.



Atomic Engine for A-Liner

Submerged pod, pictured from above, holds atomic reactor, turbine, and gearing to drive single high-speed propeller.



HIGH-SPEED PROPELLER OF NEW "SUPERCAVING" DESIGN

REDUCTION GEAR

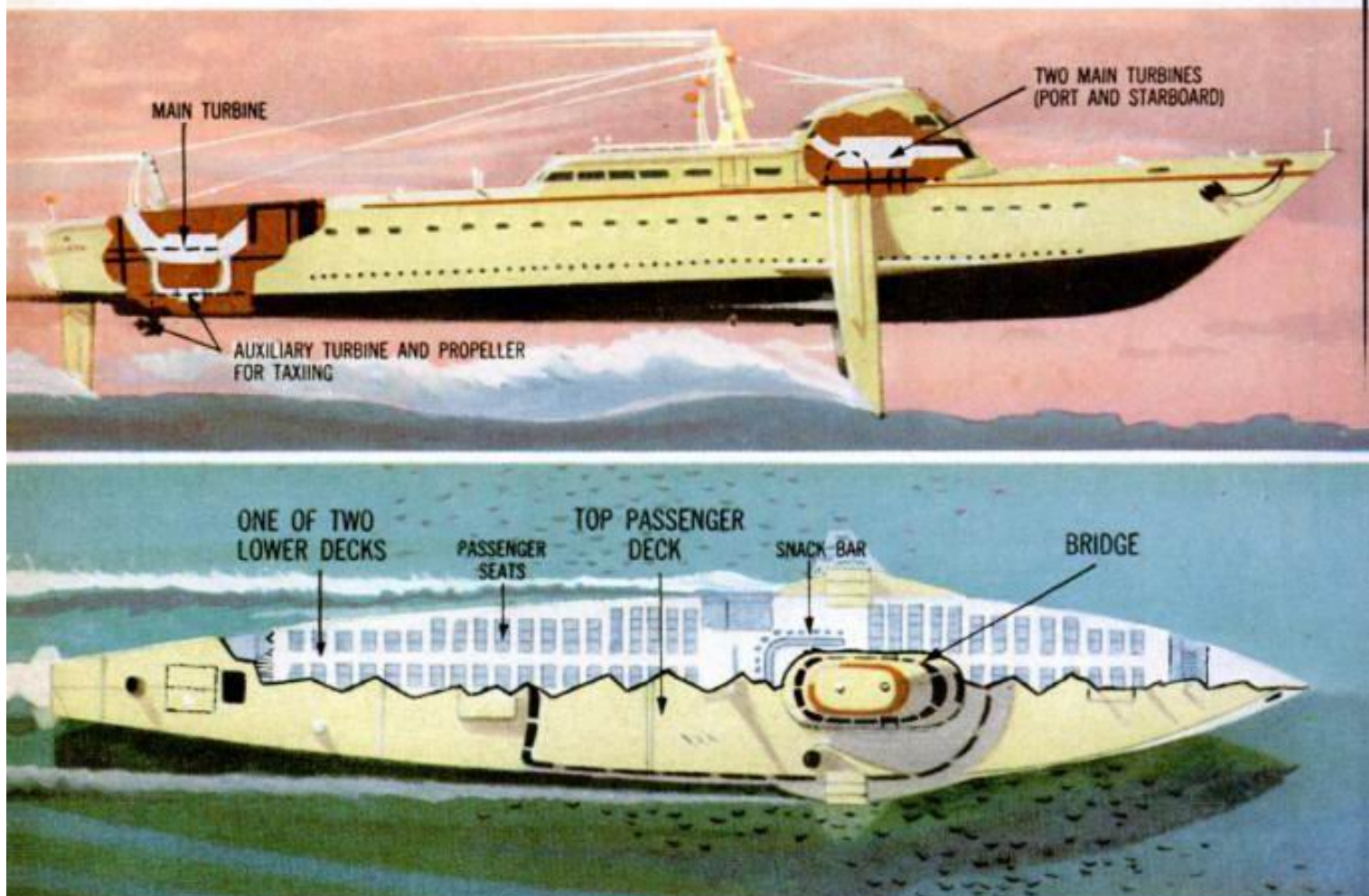
HELIUM-GAS TURBINE

CONTROL ROD DRIVE

COMPRESSOR

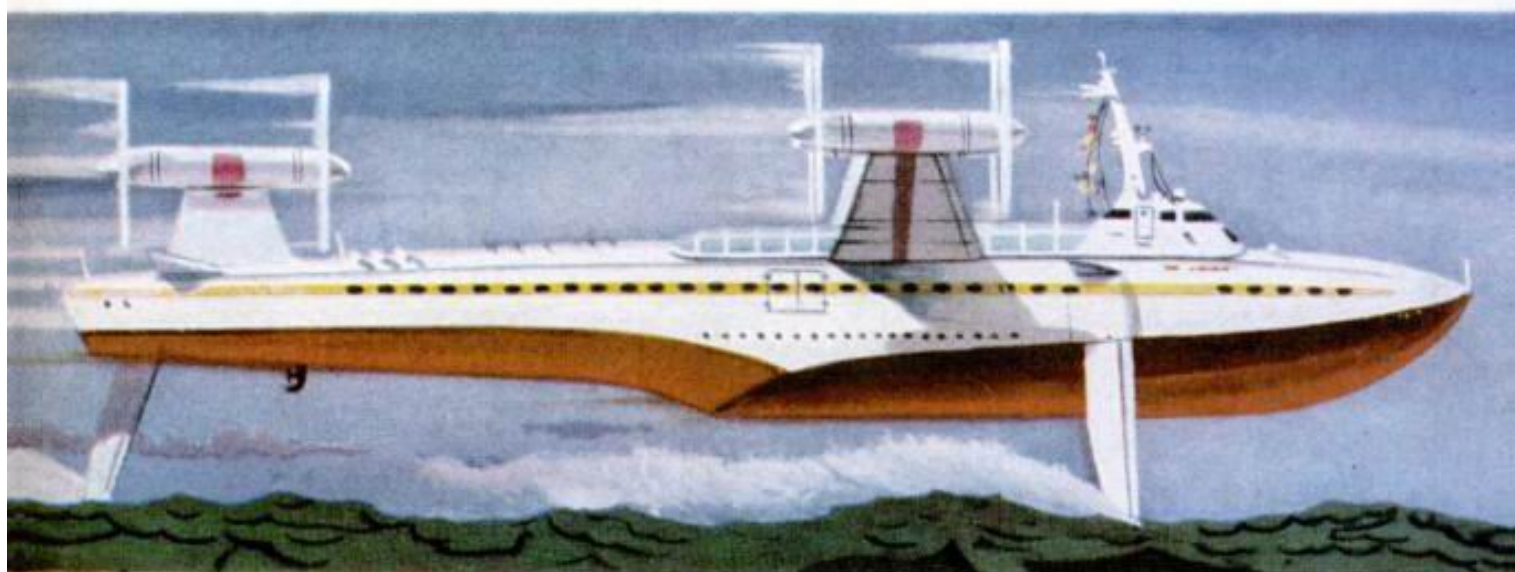
ATOMIC REACTOR HEATING HELIUM GAS

100-Knot Coastal Liner Is Fastest of Designs



THREE GAS TURBINES spin water propellers to drive this 652-passenger, 500-ton craft at 115 m.p.h. Its speed requires all-enclosed quarters, for protection from

wind. Passengers' airplane-type seats occupy two lower decks; top deck has an observation lounge and bar. Cutaway side and top views show engines and seating.



SIX AIR PROPELLERS powered by individual gas turbines drive seaplane-hulled coastal liner, in an alternate design. This craft would have same passenger

capacity, tonnage and speed as the one in upper views. Both are designed to have a cruising range of 1,200 nautical miles, which will amount to a 12-hour run.

New Deep-Diving Sub:

Our First Ferry to the Bottom of the Sea

By **EDWIN A. LINK**
Inventor and underwater pioneer

A little yellow submarine named Deep Diver has just begun making sea history. The 22-foot, four-man craft is the world's first operational submarine that puts out divers to work on the sea floor and picks them up again—a feat performed in its successful initial trials off the Bahamas.

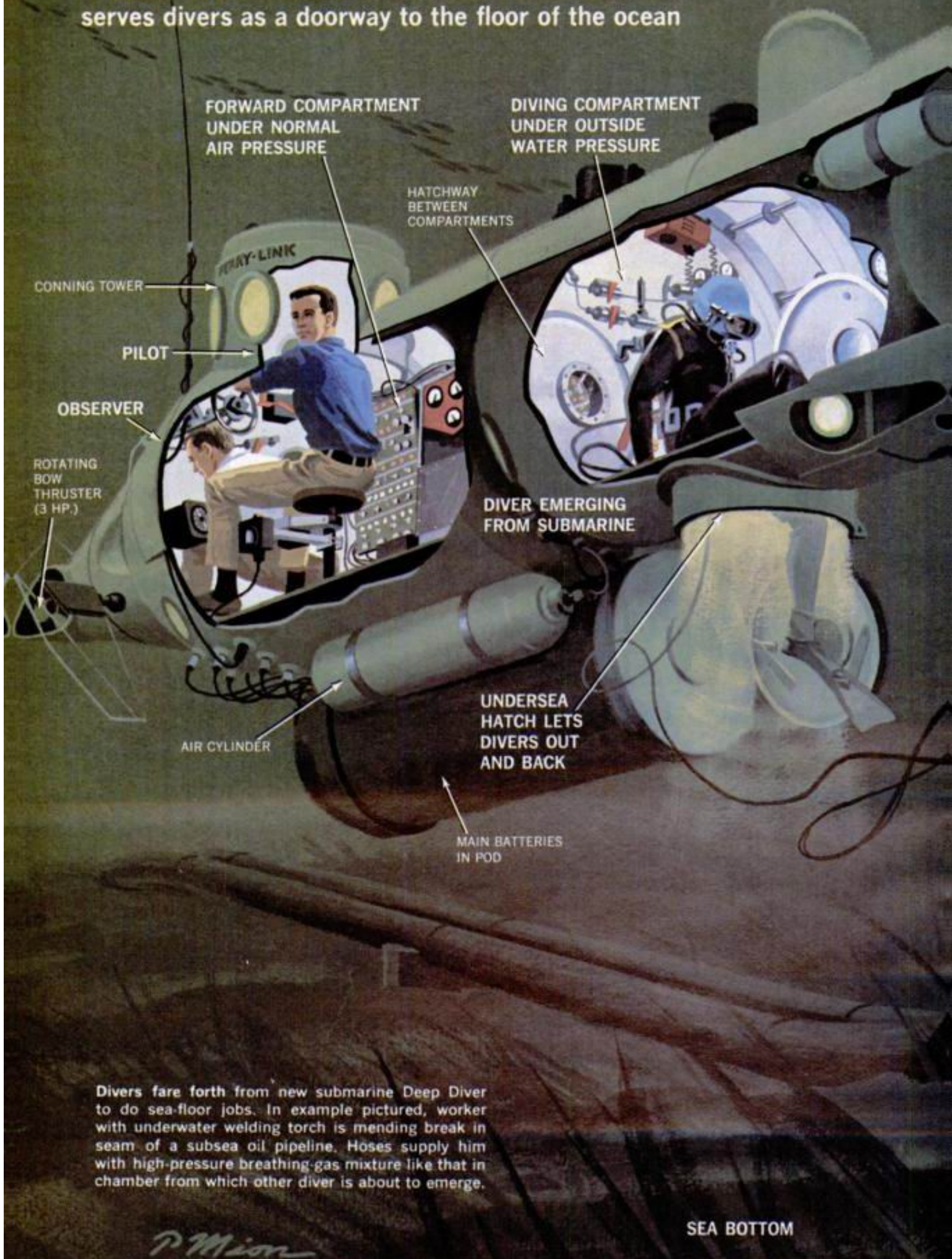
Here is a breakthrough in the conquest of the deep—a “taxi” for undersea construction and repair workers. And there are glamorous and dramatic uses—treasure hunting, lifesaving—for such a craft.

Continued

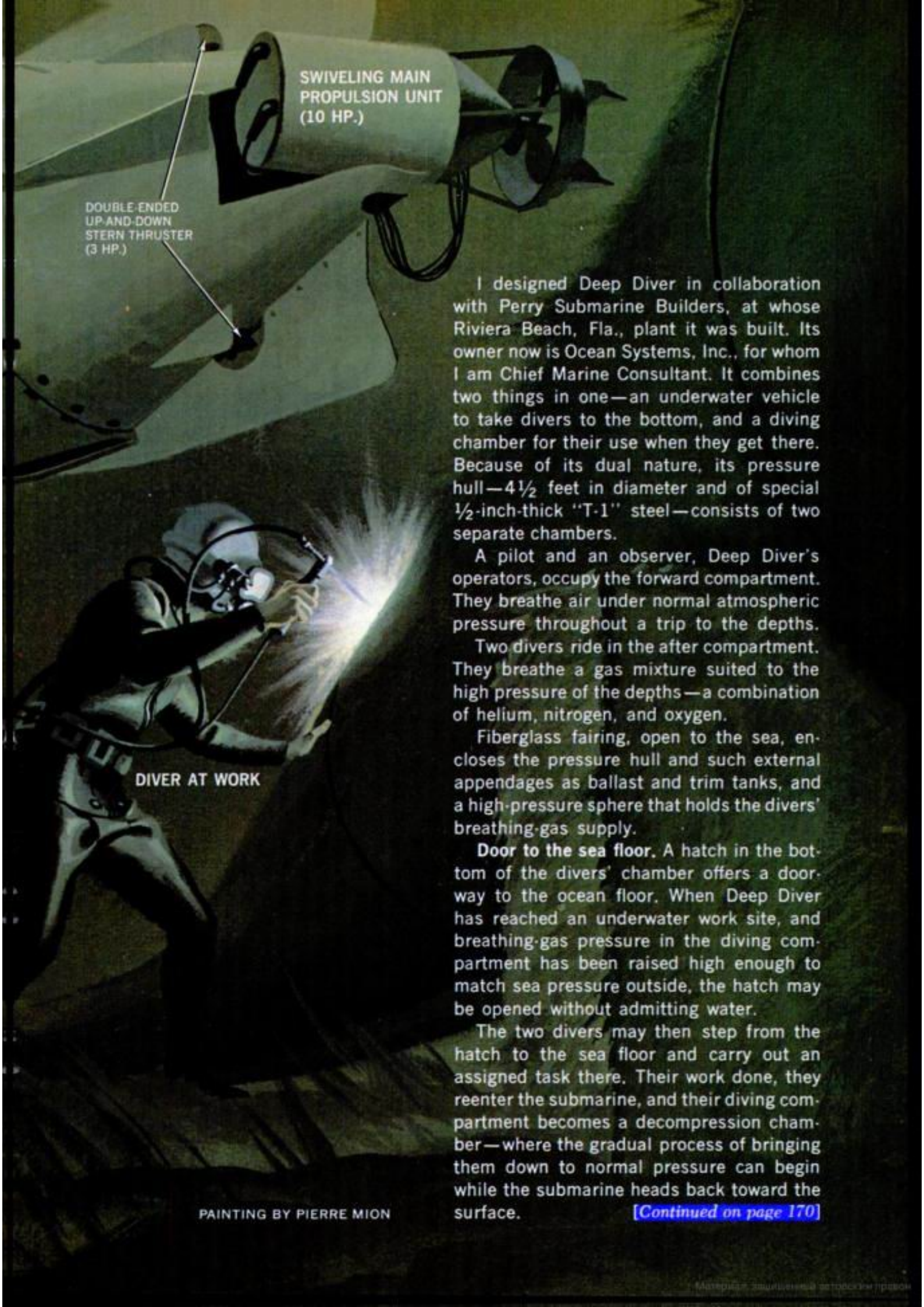


Diver has just emerged from submarine, which rests on bottom, in this underwater photo made during trial of Deep Diver off Grand Bahama, near Freeport. New undersea craft travels to and from operations area aboard a mother vessel, Link's 91-foot oceanographic yacht Sea Diver, which launches and recovers the 8¼-ton submarine with a small hydraulic crane.

A hatch in the bottom of this little undersea craft serves divers as a doorway to the floor of the ocean



Divers fare forth from new submarine Deep Diver to do sea-floor jobs. In example pictured, worker with underwater welding torch is mending break in seam of a subsea oil pipeline. Hoses supply him with high-pressure breathing gas mixture like that in chamber from which other diver is about to emerge.



SWIVELING MAIN
PROPULSION UNIT
(10 HP.)

DOUBLE-ENDED
UP-AND-DOWN
STERN THRUSTER
(3 HP.)

DIVER AT WORK

I designed Deep Diver in collaboration with Perry Submarine Builders, at whose Riviera Beach, Fla., plant it was built. Its owner now is Ocean Systems, Inc., for whom I am Chief Marine Consultant. It combines two things in one—an underwater vehicle to take divers to the bottom, and a diving chamber for their use when they get there. Because of its dual nature, its pressure hull—4½ feet in diameter and of special ½-inch-thick "T-1" steel—consists of two separate chambers.

A pilot and an observer, Deep Diver's operators, occupy the forward compartment. They breathe air under normal atmospheric pressure throughout a trip to the depths.

Two divers ride in the after compartment. They breathe a gas mixture suited to the high pressure of the depths—a combination of helium, nitrogen, and oxygen.

Fiberglass fairing, open to the sea, encloses the pressure hull and such external appendages as ballast and trim tanks, and a high-pressure sphere that holds the divers' breathing-gas supply.

Door to the sea floor. A hatch in the bottom of the divers' chamber offers a doorway to the ocean floor. When Deep Diver has reached an underwater work site, and breathing-gas pressure in the diving compartment has been raised high enough to match sea pressure outside, the hatch may be opened without admitting water.

The two divers may then step from the hatch to the sea floor and carry out an assigned task there. Their work done, they reenter the submarine, and their diving compartment becomes a decompression chamber—where the gradual process of bringing them down to normal pressure can begin while the submarine heads back toward the surface.

[Continued on page 170]

PAINTING BY PIERRE MION

HOW WE'LL TRAVEL BEYOND THE MOON

Nuclear rocket engines of mighty power, needed for our manned voyages of the future to other planets, are being perfected in current firing trials in Nevada

By DR. WERNHER
VON BRAUN

Director of NASA's George C. Marshall Space Flight Center, Huntsville, Ala.

Successful tests have lately brought a flyable nuclear rocket engine within predictable range—eight or nine years and upward of \$1 billion more, by a current estimate. Should we buy it?

Backed by the President, AEC and NASA recently asked funds to go full steam ahead. In authorization bills, Congress tentatively approved most of the amount sought for the coming year.

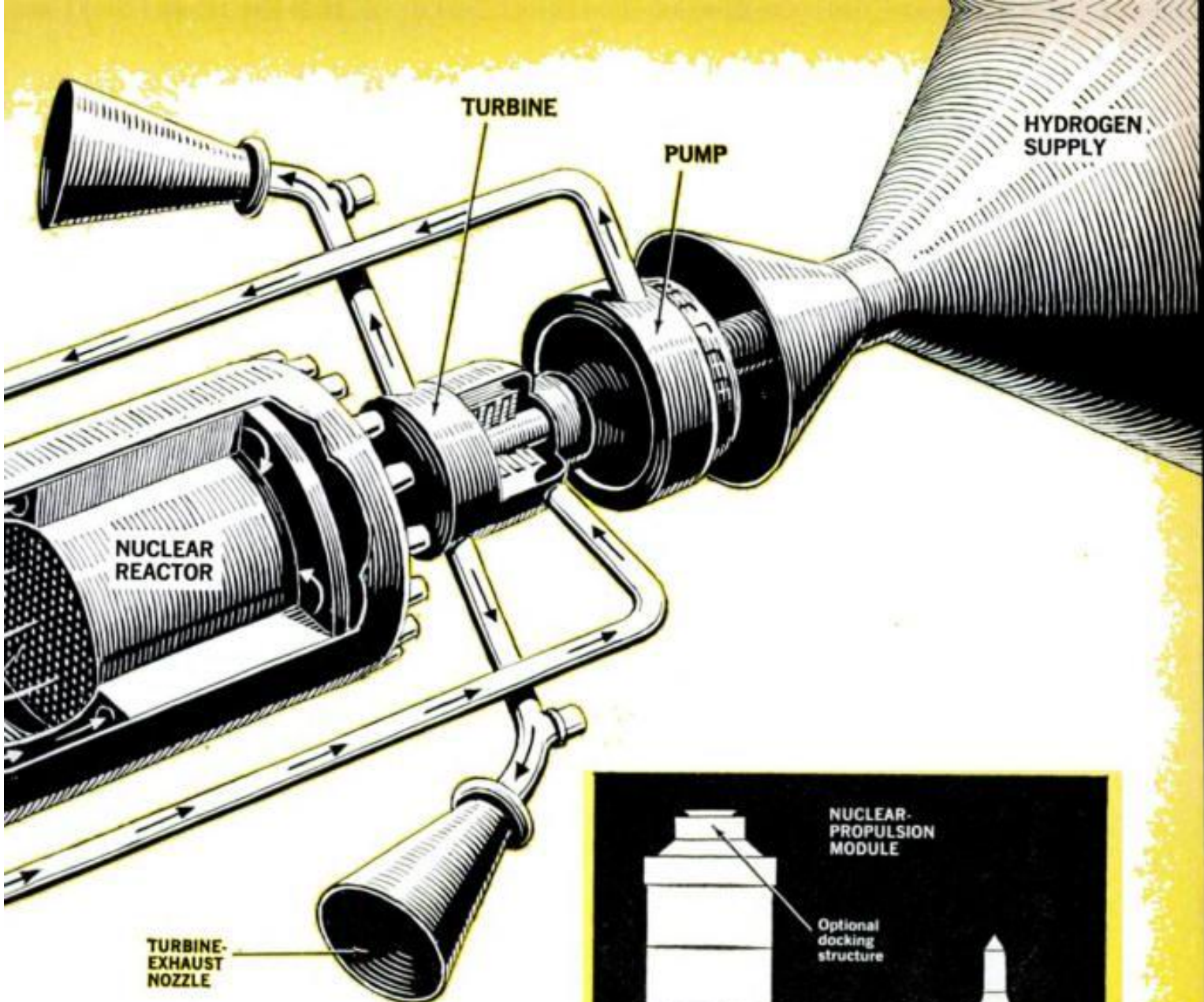
Still pending, as this was written, was Congress' final action on the agencies' actual appropriations. There was a question whether economy-enforced cuts might defer the full-scale nuclear-engine effort. But, sooner or later, it looked bound to come. Here, Dr. von Braun tells why.—The Editors.

will work this way. Hydrogen from pump, after cooling nozzle, streams through white-hot core of reactor. Blast of heated gas from nozzle propels rocket. Tapped-off hydrogen drives turbopump, and exhausts through small nozzles that can control attitude or augment thrust.



NERVA, a nuclear rocket engine with a thrust of 200,000 to 250,000 pounds and a reactor power equivalent to about 6,700,000 horsepower, will one day enable astronauts to visit the planet Mars. It will give us enough rocket power to fly a sizable group of explorers to the moon without stopover and rendezvous in lunar orbit. It will support these explorers with a cargo-carrying system that can land much greater loads on the lunar surface, and reduce the cost of transporting them.

The NERVA engine, whose name stands for Nuclear Engine for Rocket Vehicle Application, is the goal of a nuclear-rocket program jointly sponsored and conducted since 1958 by the Atomic

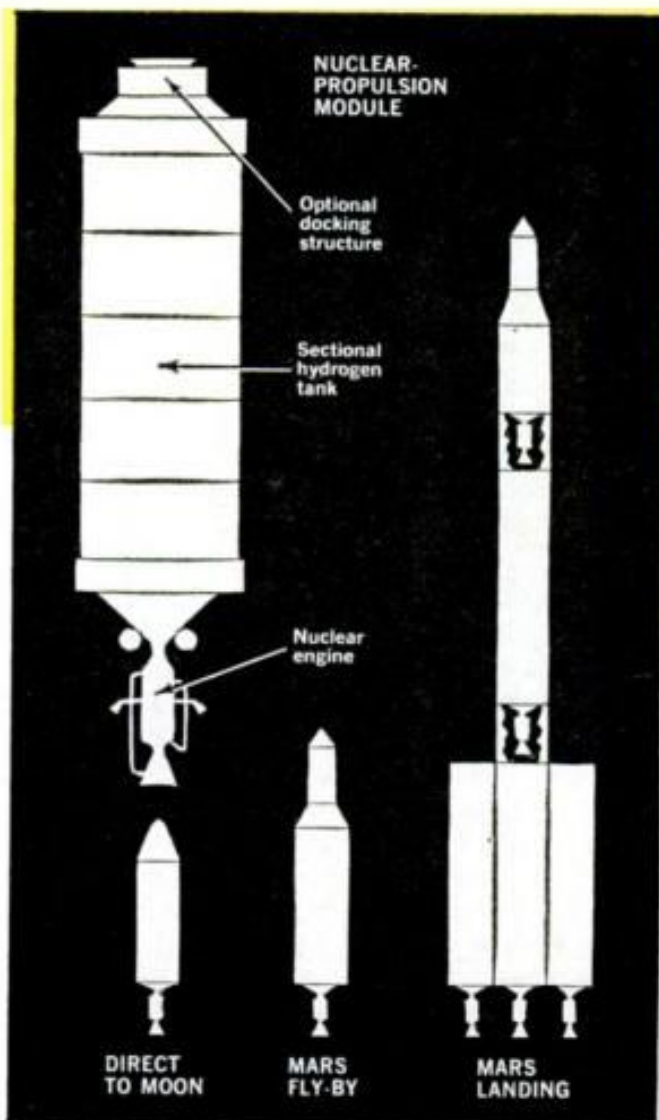


Energy Commission (AEC) and the National Aeronautics and Space Administration (NASA).

How NERVA will work. Heart of the NERVA engine will be a nuclear reactor built of graphite, and perforated by thousands of tiny channels through which hydrogen is pumped. Uranium 235, embedded in the graphite, forms the reactor's fuel. Its neutron chain reaction releases a continuous heat flow of five million thermal kilowatts, and the core of the reactor glows white-hot.

Continued

Manned spacecraft for missions shown can be made up of one or more nuclear propulsion modules, each consisting mainly of NERVA engine and tank holding 50 to 175 tons of hydrogen propellant.



Personal Rapid Transit

For a fast, private, nonstop, pushbutton, computer-controlled ride, try PRT. It's the brand-new way to get where you're going

By PAUL WAHL

There's a radically different way of getting you to work, across town, or to the airport—when *you* want to get there. It's fast, comfortable, personal—and it's here now. Sure, we've all seen pipedream concepts on paper. But this new kind of intracity transportation, called Personal Rapid Transit or PRT, is being pushed—hard—by the U.S. Dept. of Transportation.

In July, Transportation Secretary John A. Volpe announced the award of contracts totaling \$6 million for the construction of four systems. You'll be able to ride them at Transpo-72, the International Transportation Exposition at Dulles Inter-

Six-passenger Varo Monocab, suspended from an inverted U-channel guideway, rolls on rubber-tired wheels. Electric-motor-powered, this 10-foot vehicle can safely do over 60 mph. In normal operation, line speeds would average about half that speed.



No bigger than a standard automobile, the Dashaveyor comfortably seats 12, has room for 18 standees, too. A pair of 25-hp electric motors drive this rubber-tired vehicle

national Airport, near Washington, D.C., in May and June. Some of the systems you see here are already carrying passengers, or will be soon.

The government is backing PRT because it promises to be an attractive substitute for the private auto in our traffic-choked cities. How? Let's take a PRT trip and see.

Your car is waiting. After paying

along its double I-beam guideway at speeds up to 30 mph. Computerized command and control systems, as well as power pickup, are located in the wayside.

the fare, you pass through a gate and cross the station platform to board the first PRT vehicle in line. On entering the car, you push a button to select your destination, then take a seat.

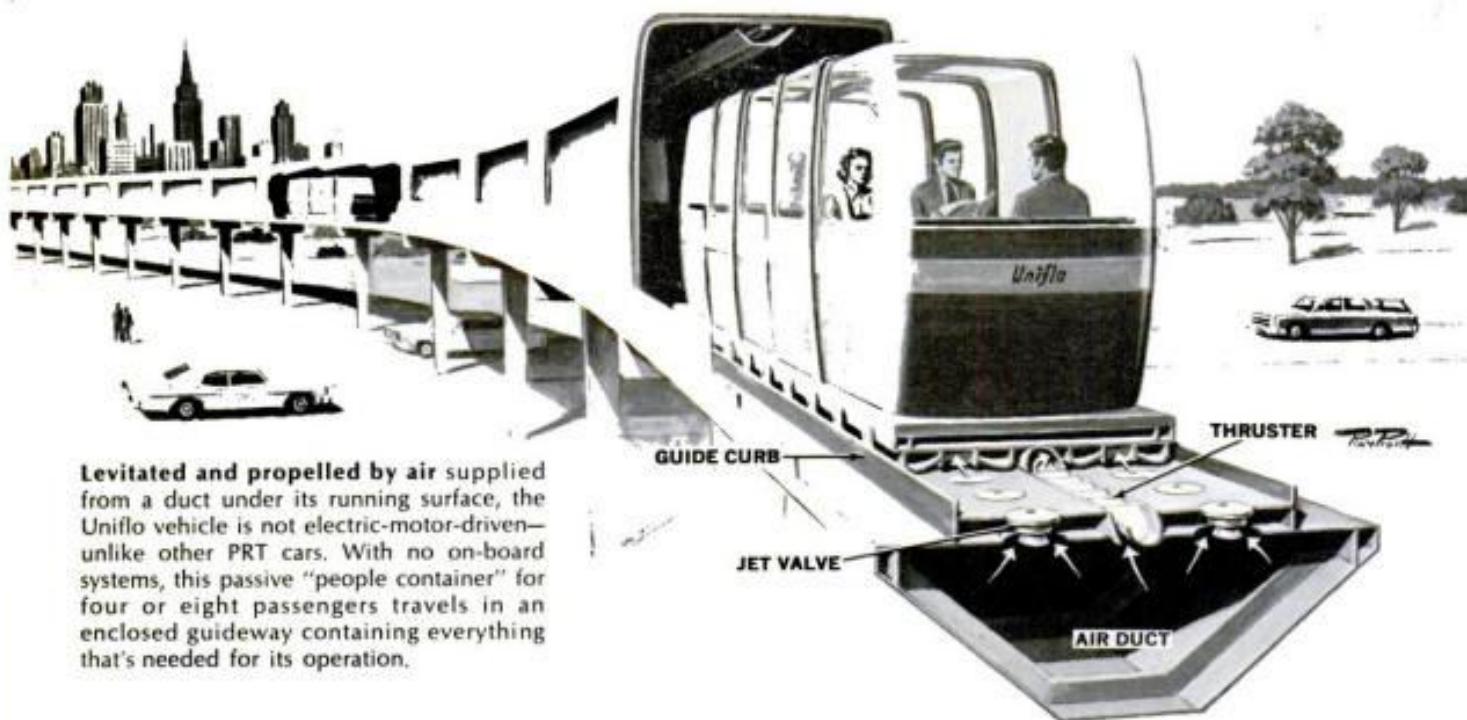
The cabin is roomy, automobile-like in accommodations, except that six-place seating is face-to-face.

Continued

W.Virginia University students will ride cars like this Boeing 17-passenger vehicle on a 2¼-mile PRT system linking University's two campuses and downtown Morgantown, W.Va. The 15-foot, rubber-tired, electric cars will move at up to 30 mph.



Slung from overhead rails or whisked along guideways, PRTs



Levitated and propelled by air supplied from a duct under its running surface, the Uniflo vehicle is not electric-motor-driven—unlike other PRT cars. With no on-board systems, this passive “people container” for four or eight passengers travels in an enclosed guideway containing everything that’s needed for its operation.

Travel amenities include—besides comfortable airliner-type seats and ample luggage space—large tinted windows, good interior lighting, air conditioning, background music (or news or plain silence), emergency communications handset, clock, and arrival indicator.

After you’re settled, the doors (similar to those of an elevator) slide closed, and the automatic vehicle moves away on the station spur, accelerating until it enters the stream of traffic on the guideway at line

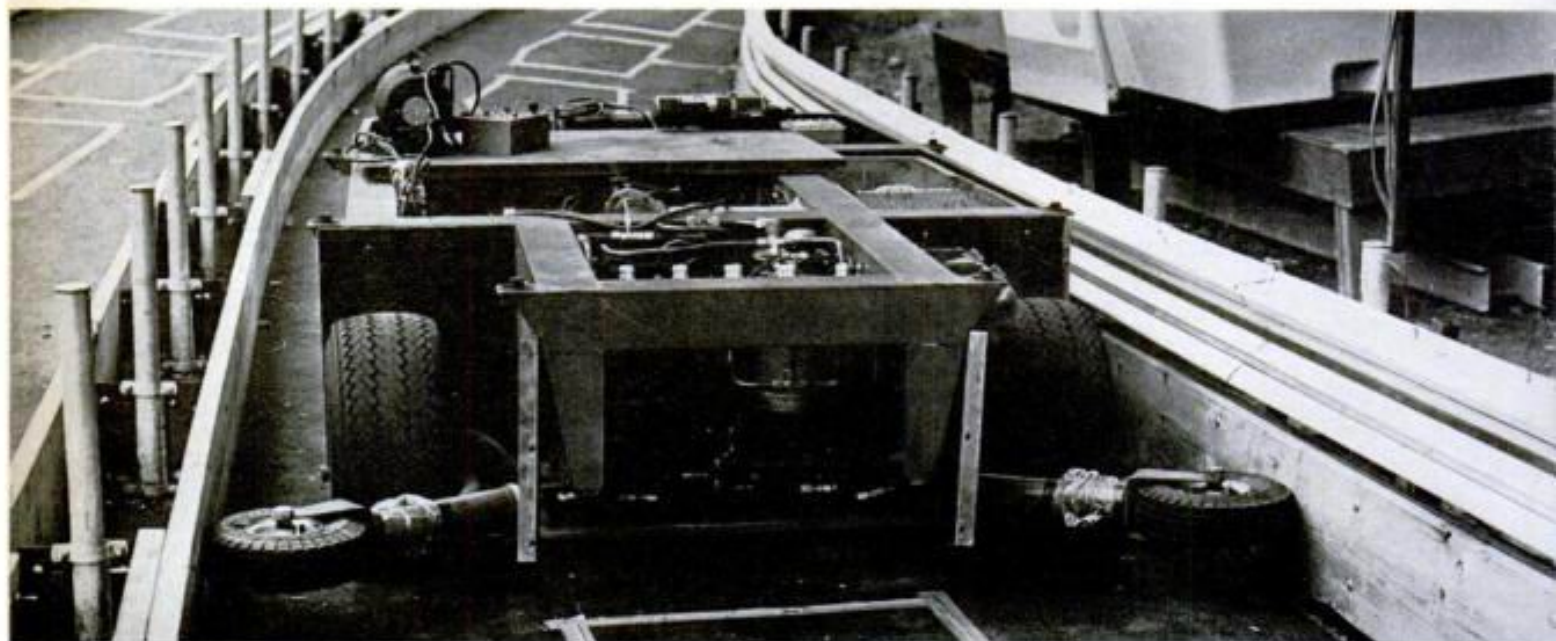
speed—about 25 mph (in city rush-hour traffic, automobiles average under 10 mph). The ride is smoother and quieter than that of a luxury car.

Approaching the preselected destination, the car switches off the main line onto a spur leading to the station, slows down, and stops at the platform. The doors open automatically and you exit into the station, having had a private express trip—at a cost somewhere between bus and taxi fares—with a central computer doing the driving. That’s PRT. The

key is exclusive use of the vehicle for a nonstop, origin-to-destination trip—on demand.

Versatile designs. Incorporated in most PRT-system designs is adaptability to either a small vehicle for the kind of personal service just described or a stretched version with greater passenger capacity for applications such as airport and university campus shuttles.

In shuttle operations, peak system loads vary greatly over short intervals, such as the arrival simultaneous-



Here’s how the staRRcar, a typical automatic PRT system, works: Essentially an electric automobile with robot chauffeur, this vehicle travels under computer control on a guideway network, providing on-demand service, nonstop, origin-to-destination—like a private car or taxicab. Basis of the Alden staRRcar is its chassis (above), containing motor, drive, braking, steering, and suspen-

sion systems, as well as electronics and servos. It rides rubber-tired wheels on a six-foot-wide asphalt pavement between guidance curbs that position car laterally in guideway, carry power and communications links between vehicle and guideway system. Vehicle guidance is accomplished through horizontal guide wheels. Computer-controlled, steering is biased right or left so that

are silent and speedy

ly of several aircraft or a change of college classes. During peak use periods, the trolley-type vehicles would be scheduled to meet known traffic requirements and operate either in local mode—making all stops—or express between two points. At other times, however, operation would be on demand, with passengers making individual selection of a station by pressing a button, as in an elevator.

Developers of some PRT systems have suggested the possibility of offering two classes of passenger service by operating both large and small vehicles on the same guideways.

Freight haulage? In addition to people-moving, the typical PRT system has the capacity to move freight—mail, parcels, baggage, refuse, etc.—in specially adapted vehicles over the same guideway network. Such haulage services are included in the Airtrans system that Vought Aeronautics Company is building for the new Dallas/Fort Worth Regional Airport.

It is essential to Personal Rapid Transit that its vehicles travel over exclusive rights of way without grade crossings or intersections. PRT cars do not stop on the main line to pick up or discharge riders—all systems provide for switching to station spurs (turnouts) for loading and unloading.

Bottom-supported PRT vehicles, whether on wheels or air cushions, can operate on guideways (typically, a shallow concrete trough about six feet wide) at grade level, in below-

Continued



Braniff's \$2 million Jetrail at Dallas Love Field is the world's first airport car-to-plane monorail system. Suspended 17 feet above the ground, its 10 electrically powered 10-

passenger cars, traveling at 15 mph, cover the ¼-mile distance between the satellite parking lot and the Braniff boarding area in under four minutes.



one guide wheel always follows a curb. Path selection (switching) is made by changing steering bias on computer command to the in-vehicle switch. Individual cars switch in or out of the stream of traffic at system speed. Prototype staRRcars are shown here at Alden Self-Transit Systems Corp. proving ground in Bedford, Mass. Molded fiberglass passenger-module (center) seats

six, is 10 ft. long, six ft. wide, five ft. 4½ in. high. Roof midsection slides open with doors (left), allowing passengers to walk into vehicle upright. Central computer facility (right) provides guide signals through a synchronous control system that produces accordion-like flow of cars around guideway; vehicles are held in preselected positions within traffic flow.



Autocab station in a department store is illustrated in this artist's concept. Suspended from overhead guideway, the two or three passenger cabs of Messerschmitt-Bölkow-Blohm PRT system are propelled by linear induction motors at about 20 mph.



Sky-Kar Transivator on its unibeam guideway carries six passengers comfortably at speeds up to 70 mph. With right-of-way requirements about the same as for above-ground telephone or power lines, this monorail could share stanchions with utilities.

Supported on air-cushion pads and propelled by linear induction motor, the TTI vehicle operates over a concrete trough guideway. Less than 100 inches long, car in foreground carries five; larger version seats 16.

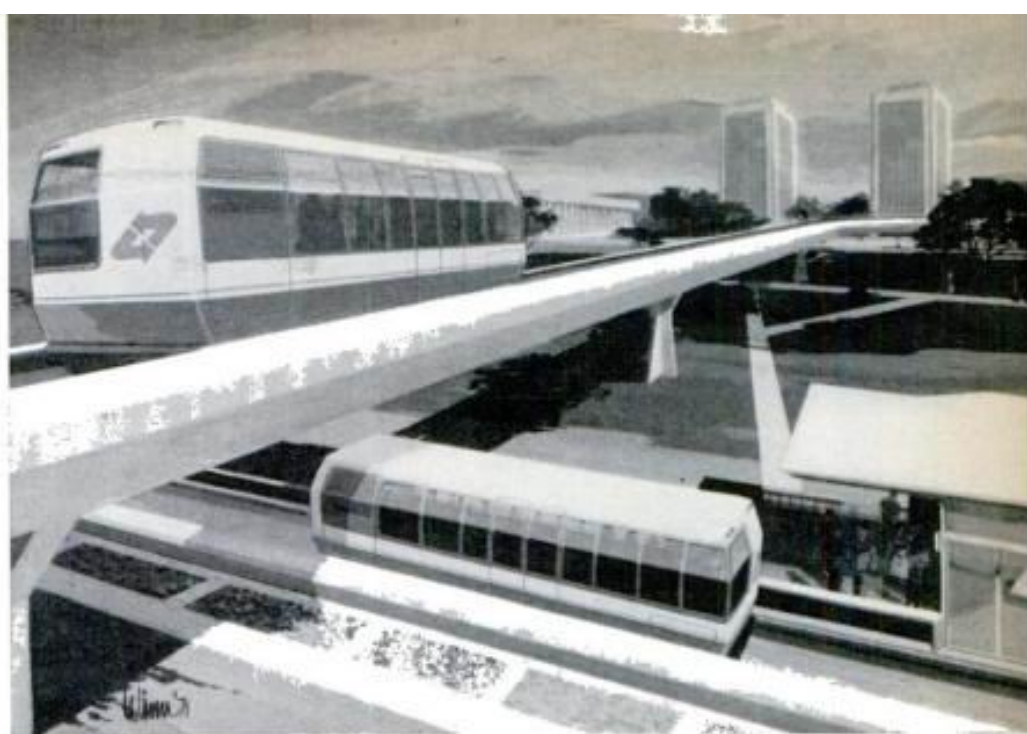
grade cuts, underground in tunnels, or on aerial structures one or two levels above the street. Monorail systems, suspended from stanchions, have attractively minimal right-of-way requirements: about the same as for above-ground telephone and power lines.

Elevated guideways. In most urban situations, they're most practical; since the right of way is largely airspace, little valuable land is needed for supporting structures. For maximum use of space, PRT guideways eventually will be multilevel. Because of the small size of the vehicles and their guideways, PRT cars will penetrate buildings, especially where stations can be conveniently located.

Although most PRT vehicles can safely reach speeds up to 60-70 mph, line speeds in intracity service are likely to be in the 20-30-mph range, which appears to be most efficient. Headway (vehicle separation) would be about six seconds. In a General Motors study of a proposed central business district system (a network with 12 miles of one-way road, 138 stations, and 3,000 "personal" cabs), it was estimated that, at a line speed of 30 mph, the average trip would take less than one minute. With a well-designed PRT system, there should be virtually no waiting time in off-hours and less than a minute during rush hours. Fast enough for you?

Super-robot trainmaster. The heart of any personal rapid transit system is the central computer facility that runs things efficiently and economically, making it practical. This super robot not only drives all the cars on the line, adjusting speed and sepa-

A quarter buys ride on this space-age automated trolley when the new Dallas/Ft. Worth Regional Airport opens in 1973. Singly or in trains of two, these 40-passen-



Ford's ACT—"Activity Center Transportation"—vehicle is electric-motor-driven, has automotive-type suspension and rubber tires, cruises at 30 mph on an elevated

guideway. Prototype car will carry 24 passengers, 12 of them standees. Planned are similar six-, 12-, 18-passenger models to operate interchangeably on same guideway.

ration to meet traffic conditions, but also handles vehicles distribution and scheduling, contingency and emergency planning, performance monitoring, maintenance management, and just about everything else that can't be entrusted to foul-up-prone people.

As you'll note from the accompanying illustrations of representative systems, PRT vehicles are roughly divided into bottom-supported (wheeled or air-cushioned) and suspended (monorail) types. Except for a couple using linear induction motors (LIM) and one air-propelled maver-

[Continued on page 136]

ger Vought Airtrans electric vehicles will travel rubber-tired over 12 miles of U-shaped concrete guideways. Dual-mode cars are manually driveable off guideway.



Unique in its ups and downs, Trans-Seat operates vertically as well as horizontally. The six-passenger electric cars, only six feet long, have steel wheels and run on narrow-gauge RR tracks on elevated structures or underground tubes. An escalator-like conveyor moves the vehicle from one level to another.



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THE *What's New* MAGAZINE

PRT: New Way to Get Where You're Going

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Consumer's Guide to
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How Good Are Those
New Cassette Tapes?
Listening Jury's Report
on the New
Cassette Players
New Zero-Error
Turntables

To Be a Safer
Winter Driver
EARN TO SKID!

We Drive the New
**WILLIAMS
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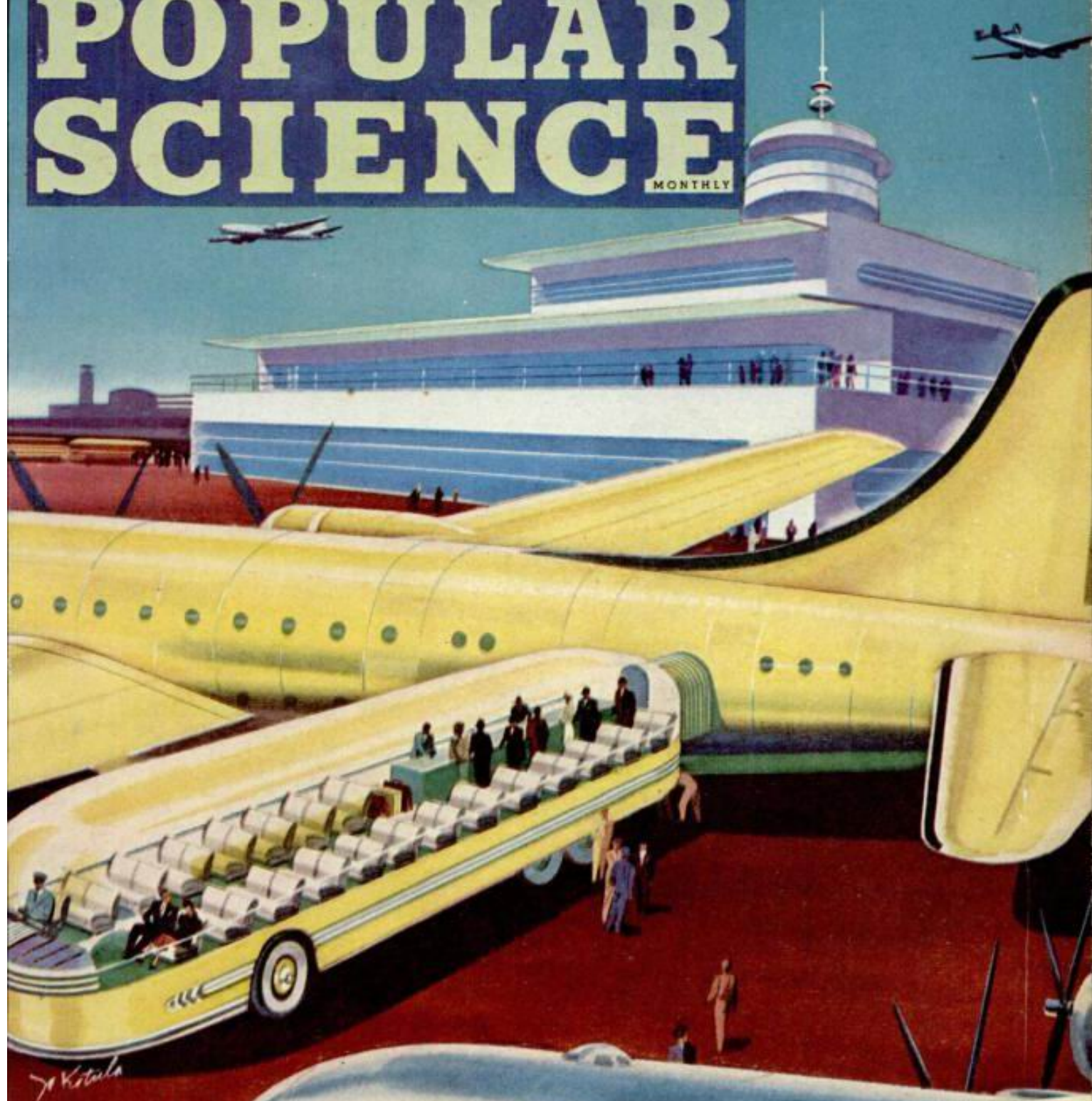
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8 PAGES
ABOUT *AIR-AGE DIRIGIBLES*
HOW WE FIGHT JAPAN WITH FIRE

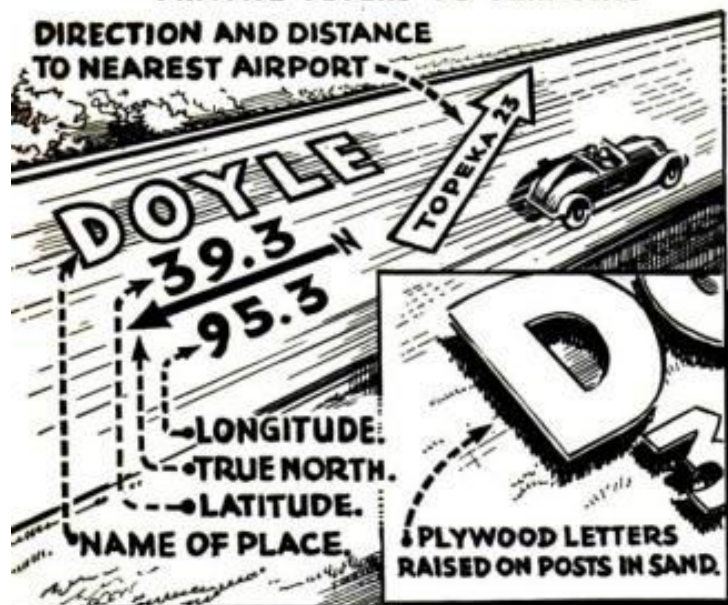
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MONTHLY



YOU WON'T BE ABLE TO FLY WITHOUT LANDING FIELDS PAGE 74
WHY JAPAN WILL LOSE ON LAND PAGE 130

MAR. 25¢



Under the CAA Air Address System, every city, town, and village in the United States eventually will be marked for identification from the air. Markings may be painted on highways or outlined in crushed stone, evergreens, or plywood

private pilot, riding cross-country, keeps a worried ear attuned to the throb of his engine and a bilious eye on the weather, because the spots where he can make emergency landings are few and far between. On the average, he has a place to sit down only once in every 1,294 square miles.

Even that figure is misleading, because landing fields are bunched around the more populous areas, leaving the great open spaces arid of facilities. Moreover, fully half the existing fields are indifferently maintained. In bad weather they are mud holes. They are badly marked. A pilot needs a telescope to spot them from the air.

We are going to have a lot more places where airplanes can take off and land. More than 60 percent of the money to be poured into standard airports and lesser landing facilities is earmarked tentatively for improving ports that can be used by airliners.

Here is a hypothetical case history of what expanded air-line service would mean: Two cities of 100,000 population lie 600 miles apart. Between them, evenly spaced, are five communities of 25,000 each. If a transport plane makes a stop at one of those five communities on its flights between the two big cities, traffic between the terminals increases by 70 percent. If two stops are made at intervals of 200 miles, the traffic increase is 160 percent. If stops are made at all the intermediate communities, the traffic between the two terminals increases sixfold.

The rest of the money earmarked for landing-field construction and improvement will go to the private flyer. Counting all the projects in the long-term plan, he will

have a minimum of 5,000 ports. Possibly, with the inclusion of intermediate landing "strips," he will have as many as 6,000 to 10,000 stopping points. If he had 8,000, he would enjoy a landing area in every 372 square miles.

The nation's smaller communities will benefit most from the airport program. Of the new airports planned, only 150 will be built in cities of more than 50,000 population; only 59 in cities of between 25,000 and 50,000; but 515 in cities of 5,000 to 25,000, and 2,326 in towns of less than 5,000.

What neither industry nor Government knows is just what America will have when the building project is complete. Airplane design, as to both size and performance, which largely dictate airport design, is in a state of flux. The commercial air lines are only guessing about what kind of equipment they will need a decade, two decades, from now. Manufacturers are only guessing about how many people will buy planes for their personal use.

INGENIOUS ACCESSORIES WILL

Redrawn by B. G. Seielstad
from "The Aeroplane"



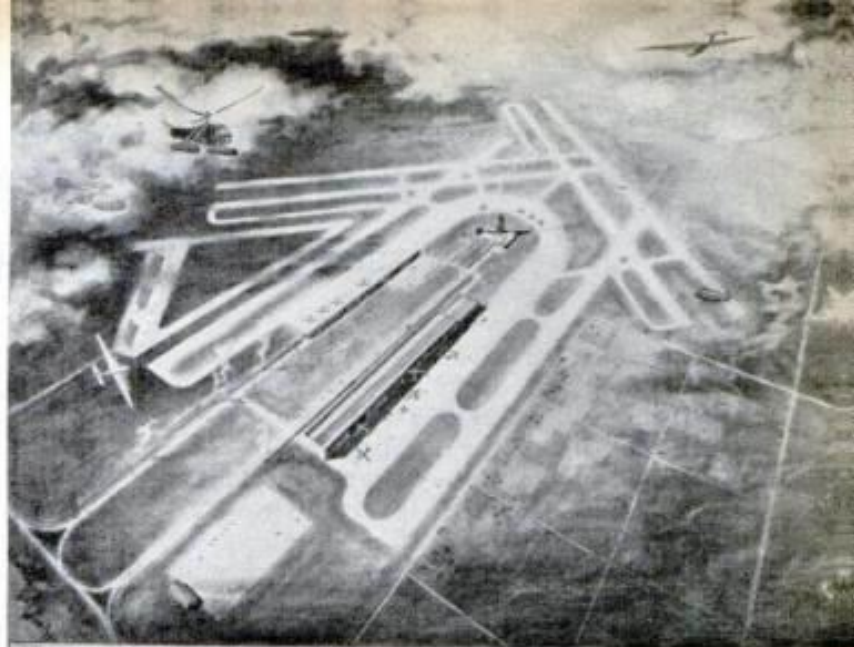
COMPARTMENT LOADING, using containers that form sections of the fuselage, has been suggested for speeding the handling of cargo. Sections would be filled at freight terminals and brought by truck to the airport, where cranes would exchange them for the incoming containers



CUSTOMS UNIT, with luggage conveyor and platform, is towed to meet arriving airliners

Will the transoceanic airliners be behemoths of 200 tons gross weight, as compared with today's 40-ton standard versions? Will the domestically used transports carry 30 passengers or 100, and on hops of what length? How many coast-to-coast nonstop or one-stop schedules will be needed as against "local" schedules stopping every 50 or 100 or 200 miles? Will the take-off and landing speeds of transport planes require surfaced runways a mile in length, or a mile and a half, or two miles?

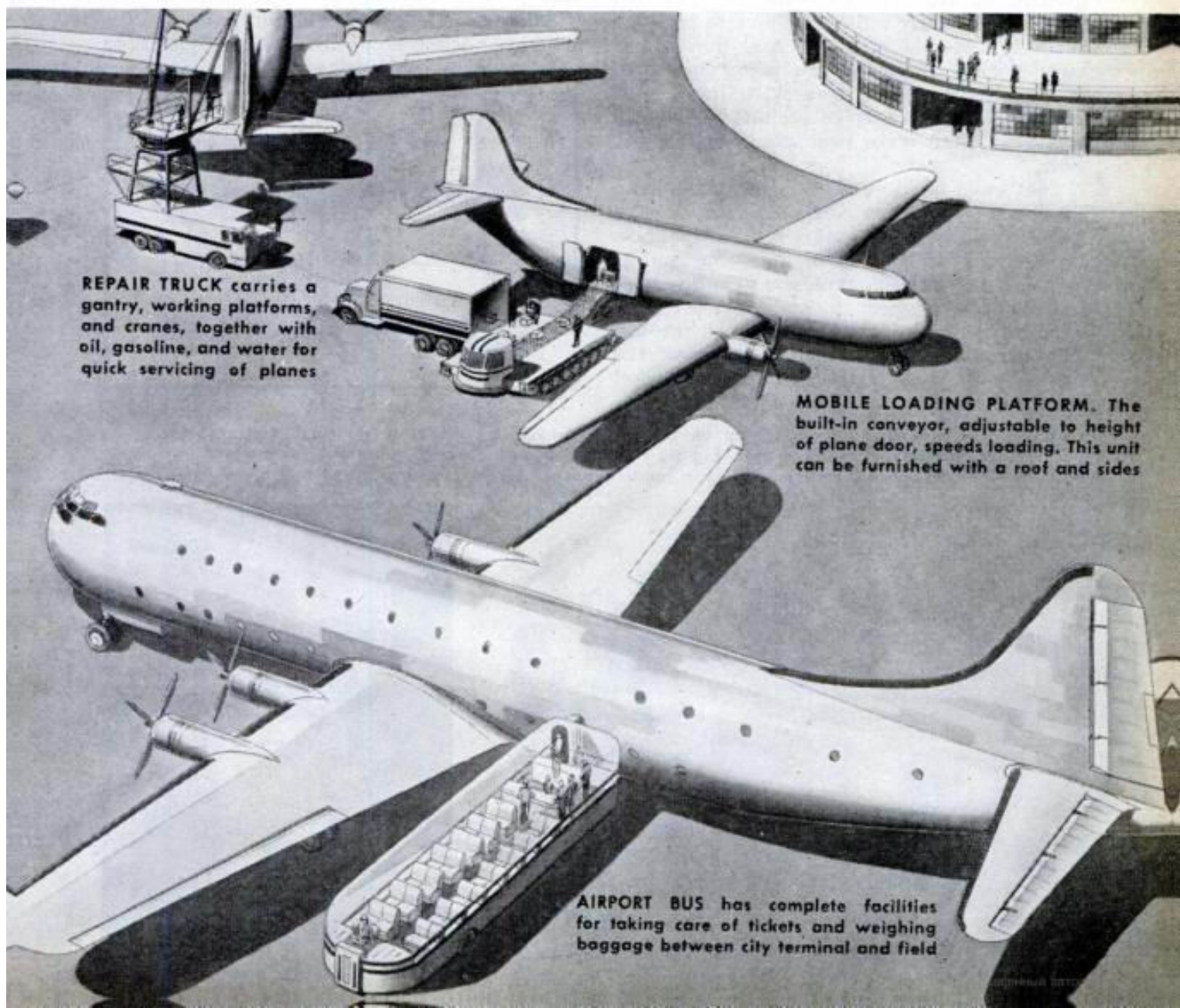
Will private-owner aircraft be standardized in the conventional fixed-wing design, or will they be largely of the whirling-wing type like the helicopter and the Auto-giro? If of the fixed-wing type, will better engineering progressively reduce their take-off and landing runs, *(Continued on page 211)*



OKLAHOMA CITY MID-CONTINENT AIR TERMINAL

POSTWAR COMMERCIAL AIRPORT. Facilities must be provided for handling the huge skyliners that will shuttle across the continent and the oceans. A fine example of progressive thinking in this field is the project of the Oklahoma City Chamber of Commerce pictured

SPEED THE DISPATCH OF PLANE PASSENGERS AND CARGO

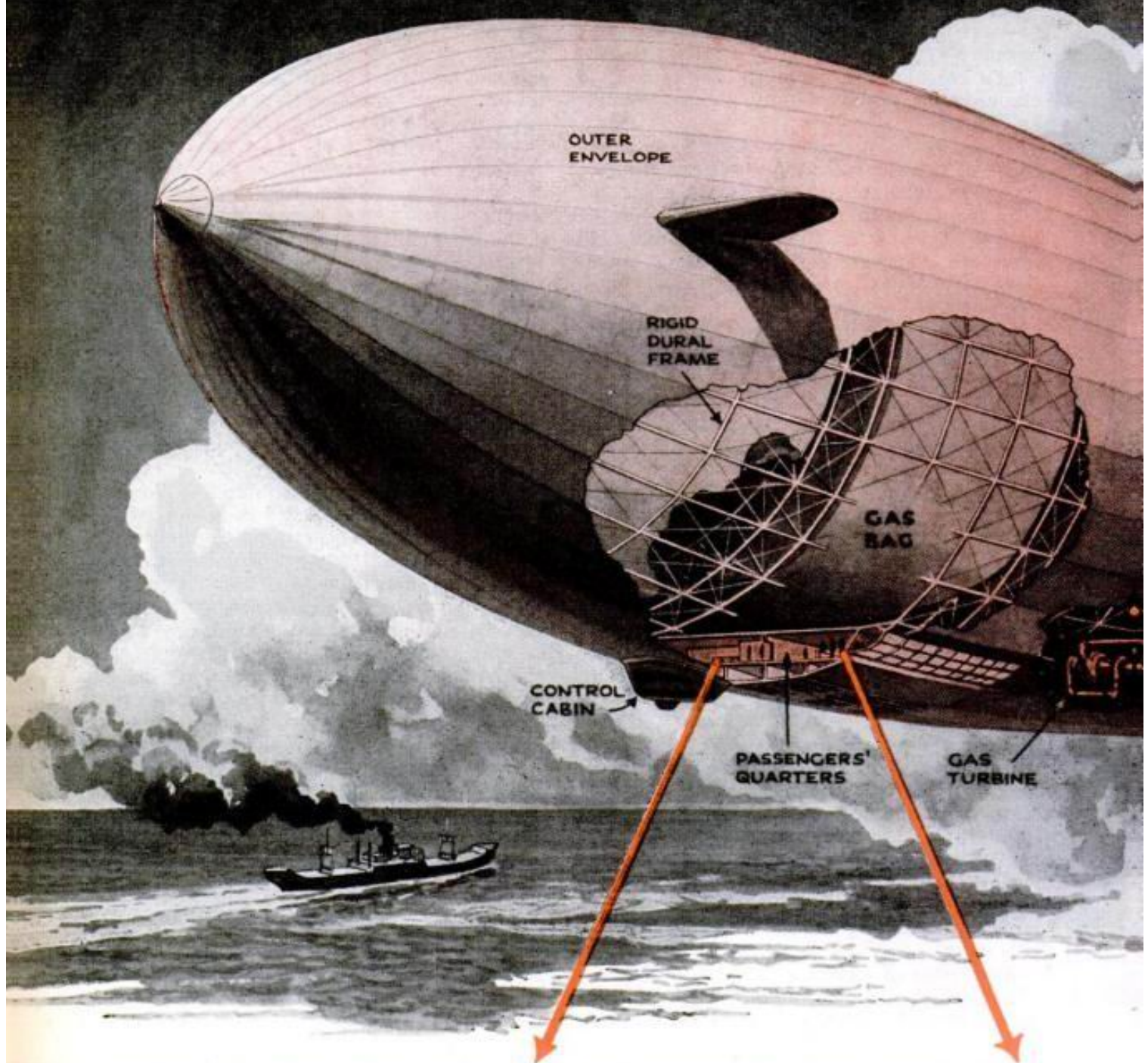


REPAIR TRUCK carries a gantry, working platforms, and cranes, together with oil, gasoline, and water for quick servicing of planes

MOBILE LOADING PLATFORM. The built-in conveyor, adjustable to height of plane door, speeds loading. This unit can be furnished with a roof and sides

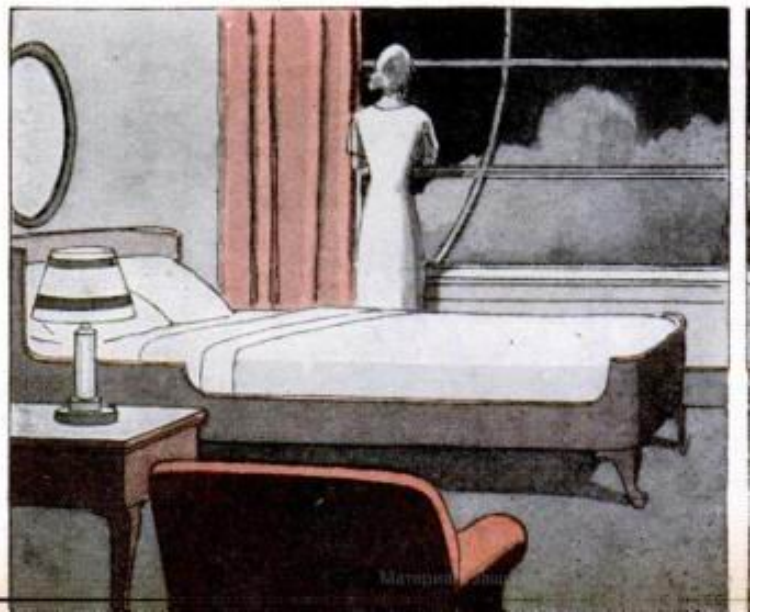
AIRPORT BUS has complete facilities for taking care of tickets and weighing baggage between city terminal and field

WILL SHE BE QUEEN OF THE SKY?

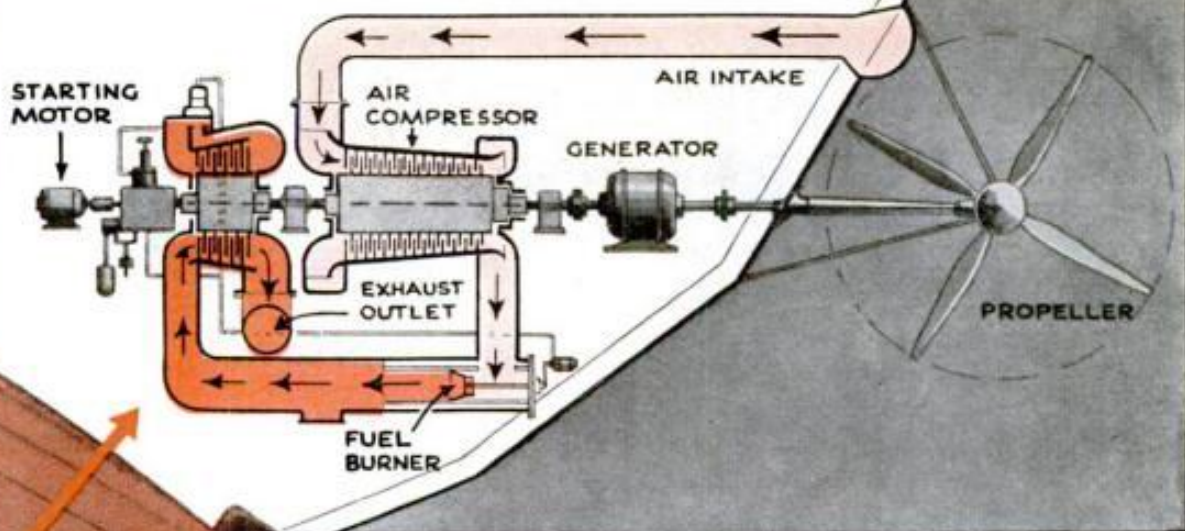


Dirigibles of the future will have spacious dining rooms and inclined windows for perfect observation. The lack of vibration will make eating a pleasure.

Real stateroom comfort aboard tomorrow's dirigibles promises delightful traveling. Seasickness will be minimized through steadiness of the airship's flight.



Many American airmen predict the coming dirigibles will be driven by gas turbines, noted for their efficiency, power, lightness, and dependability.



WATER
CONDENSERS

FOUR
PROPELLERS
ON EACH SIDE

No radical changes in the exterior appearance of dirigibles are foreseen. Designers feel the postwar ship will closely resemble the familiar cigar-shaped craft. However, many internal refinements and structural improvements are certain. Technical developments will add to safety, economy, and efficiency of operation.

ment should have a payload of 100 passengers and 20,000 pounds of mail and express when inflated with helium."

American designers were the first to move the engines inboard to reduce drag, and to swivel the propellers for better control. Now it is suggested that both engines and propellers be placed in a central tunnel running the length of the ship, which would further reduce drag and improve control, and at the same time add a jet-propulsion effect. Also, it seems likely that tomorrow's airships will be using gas turbines for power, thus greatly increasing efficiency. These changes, experienced lighter-than-air authorities believe, could increase airship cruising speeds to as much as 125 miles an hour.

As for costs, it is worth noting that our whole military airship program up to 1941 cost less, for instance, than LaGuardia Field, New York City's airport. This included the

building of three rigid airships—the *Shenandoah*, the *Akron*, and the *Macon*—construction of two airship docks and bases, one on each coast, and five mooring masts, one on a ship for sea moorings. This airship program cost \$30,000,000. LaGuardia Field cost \$42,000,000.

Finally, America's monopoly on helium makes an American airship program a "natural." Add to that the fact that its shipment and storage are both complicated and expensive, which means it probably will remain here. Helium has nearly 93 percent as much lift as hydrogen, is an inert gas, and is foolproof and virtually accident-proof. Given capable handling, the weather information now available, and intelligent operation, American-built helium-filled airships would seem to demand a place in any international program of postwar commercial aviation.

How science plans to tap sun power from the sea

Our oceans are huge 'batteries' that store solar heat. Researchers are working on systems to convert that heat into electrical energy. Best of all, scientists say there'd be no pollution.

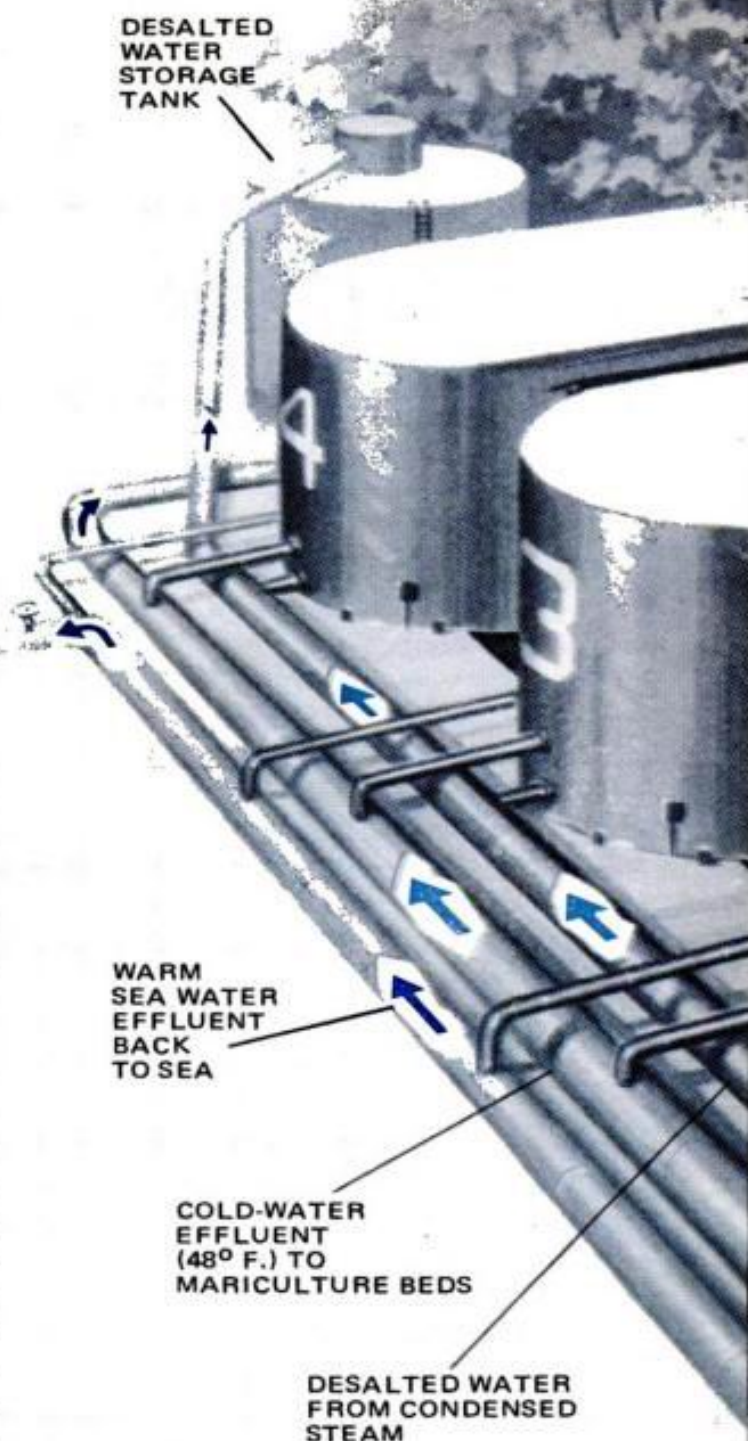
by Franklynn Peterson

Many scientists concerned with our energy problems say atomic power is not the long-term answer. They look instead to the ultimate source of energy in our universe—the sun. Though their proposals might have seemed visionary some years ago, they are regarded seriously today—seriously enough for the National Science Foundation to fund research studies.

Several groups of scientists now propose that we exploit sun power by tapping energy from the oceans. Oceanographers long have been fascinated by the fact that, throughout our oceans, surface waters have a temperature of about 80°F. while temperatures half a mile down hover close to the 40°F. mark.

Engineers and physicists look at such differences of temperature as thermal energy ripe for conversion to more convenient forms. That 40° difference represents the same "storehouse" of potential energy as a 350-foot waterfall. Harness the heat differential in the Gulf Stream as it flows through the Florida Straits between Miami and the Bahamas, say scientists, and you could produce enough electricity to equal the total now used in the United States.

The sun's rays warm the ocean's surface to near 80°F. well beyond the tropics. And deep seawater flows in chilly currents from the poles toward the tropics. There are many places on the globe where warm surface water and cold depths occur within only a few miles of land because of a steeply sloping



The Othmer system as it might appear installed on the shore of a Caribbean island. Some of the cold ocean water, used to condense the steam, would be used to grow shellfish in the big mariculture beds.

NET POWER:
10,000 KW.

MARICULTURE BEDS

GENERATOR

BOILER UNIT

CONDENSER UNIT

STEAM

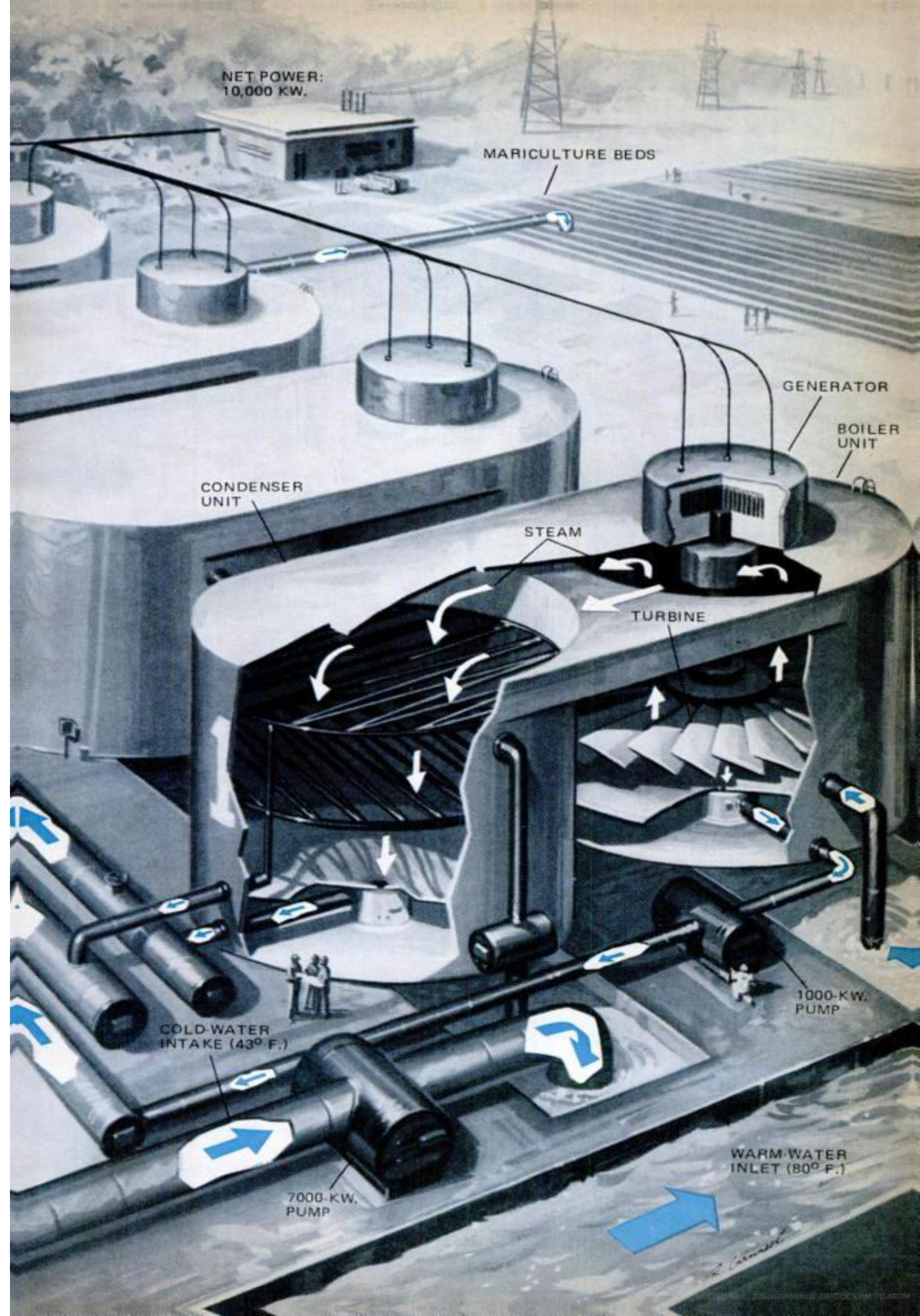
TURBINE

COLD-WATER
INTAKE (43° F.)

1000-KW.
PUMP

7000-KW.
PUMP

WARM-WATER
INLET (80° F.)



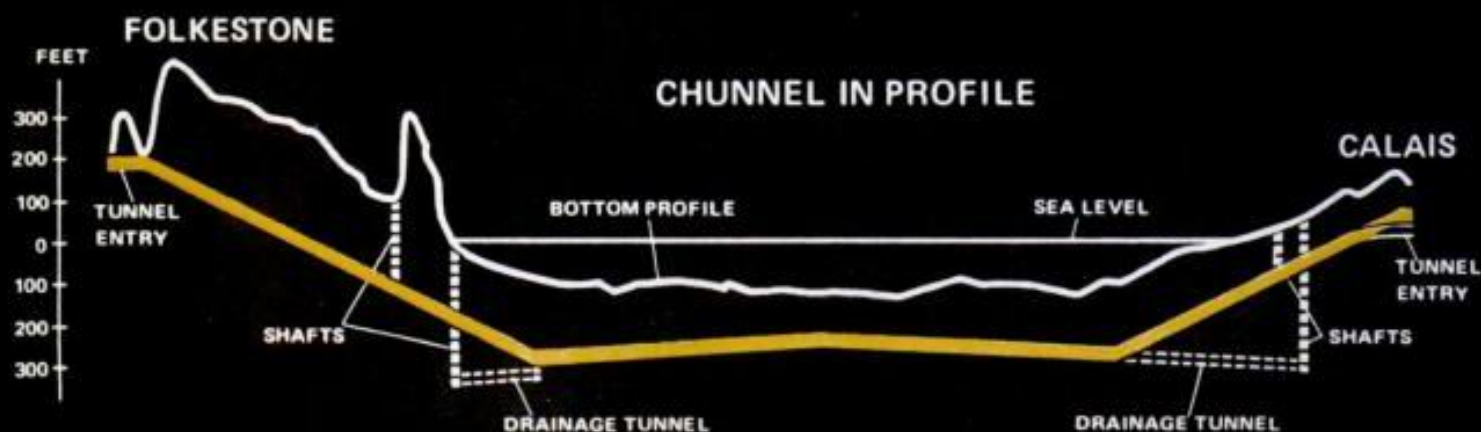
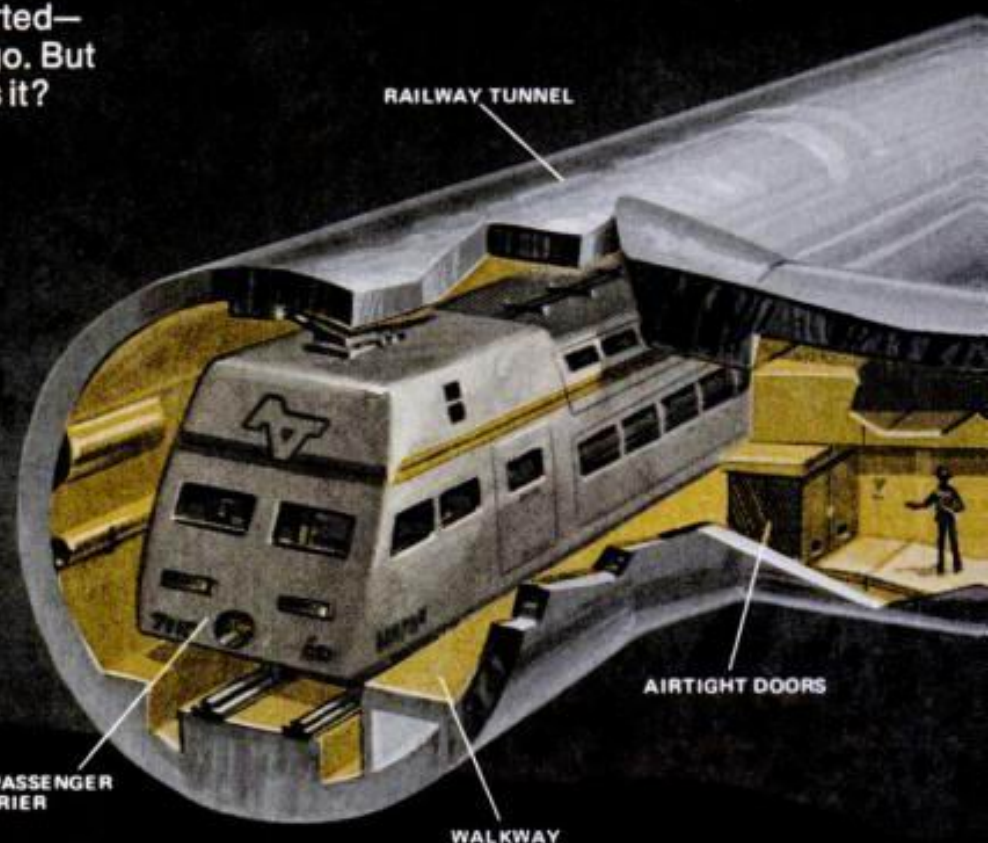
Is the Chunnel for real?

For over 100 years the British and French have planned to link the two countries with a tunnel running under the English Channel. Digging was actually started—and abandoned—some 90 years ago. But now a new effort is under way. Or is it?

by J. A. Maxtone Graham

Only 22 miles of water separate England from the European continent. Each year, millions of people cross the English Channel and millions of tons of goods are shipped over it. It's safe to say that if 22 miles of water separated two such busy parts of the United States, some kind of fixed link would have been provided at least 50 years ago.

But the way things stand, an Englishman bent on visiting the Continent is confronted by a bewildering variety of travel meth-





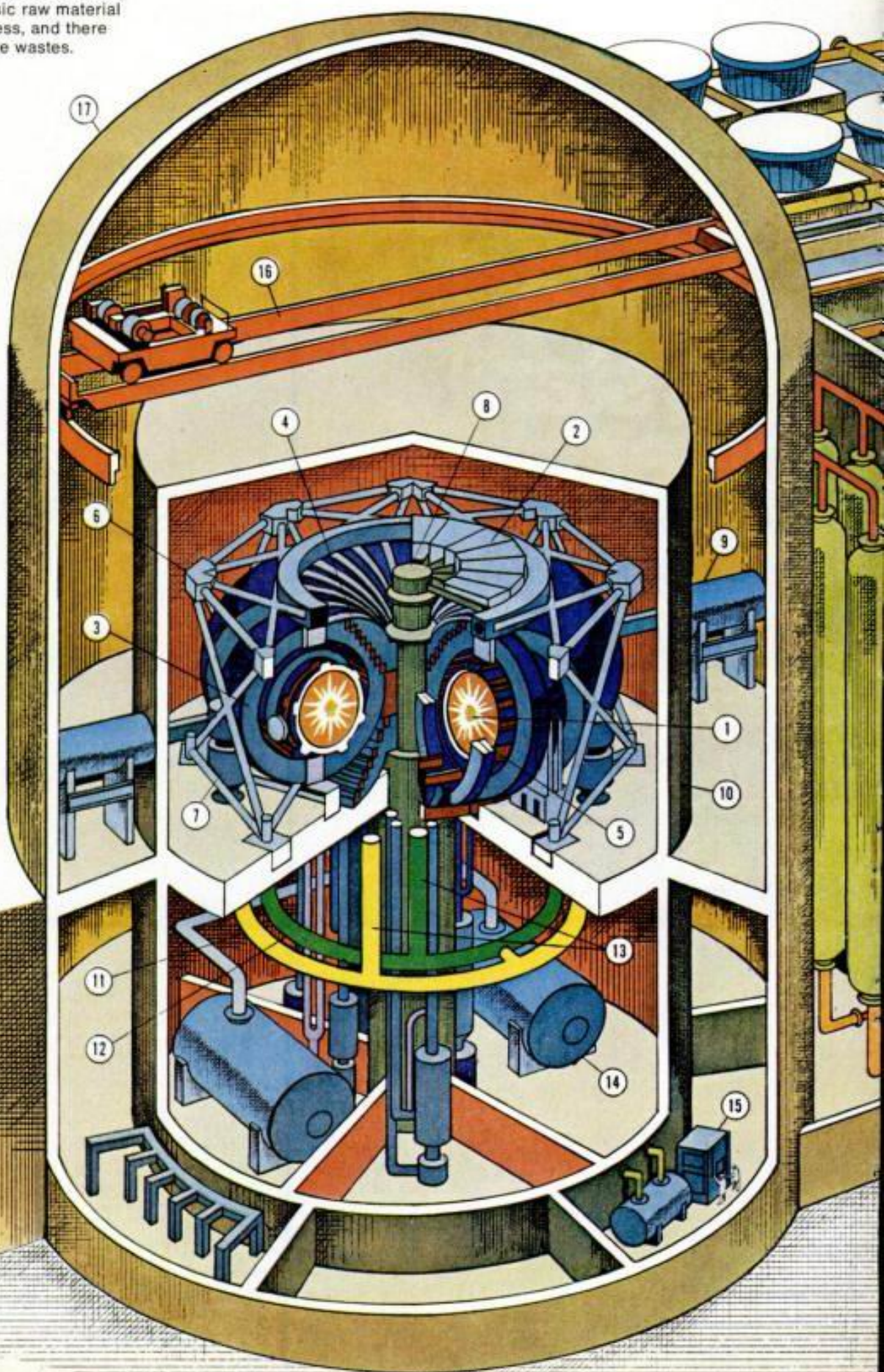
Proposed plans call for a Chunnel made up of three tunnels—two for trains and one from which the others could be serviced. Trains capable of carrying as many as 260 autos would shuttle between England and France, making the run in some 35 minutes. Total cost would be about \$2 billion.

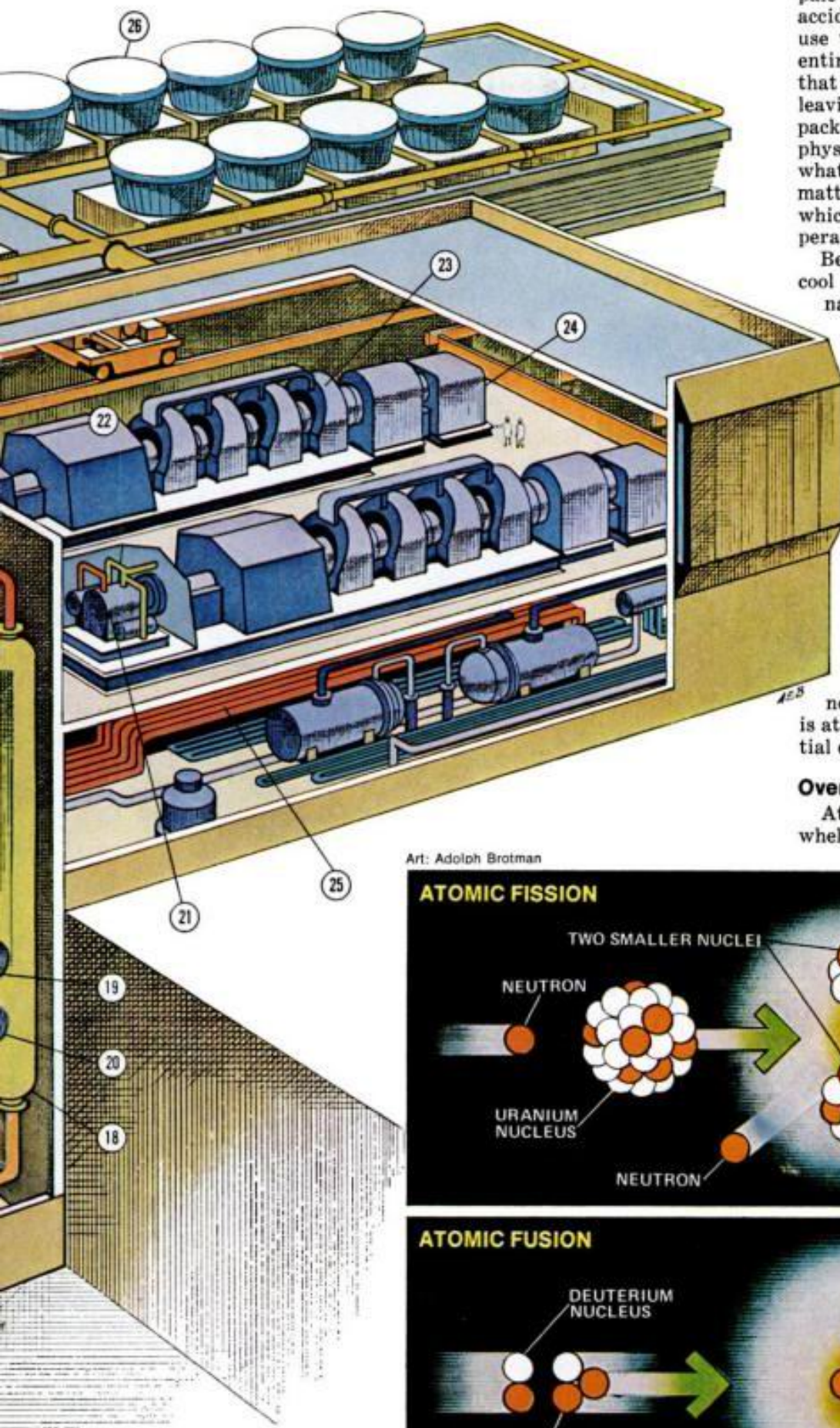
A single gram of matter yields a huge wallop

The Princeton Large Tokamak is designed to heat and squeeze plasmas in its doughnut-shaped torus until fusion occurs, releasing torrents of energy. The basic raw material—water—is virtually limitless, and there is no problem of radioactive wastes.

Tokamak elements

1. Torus vacuum chamber
2. Shielding
3. Toroidal field coil
4. Ohmic-heating field coil
5. Equilibrium field coil
6. Torque frame
7. Vacuum pump
8. Central column support
9. Fuel injector
10. Shield
11. Helium outlet header
12. Helium inlet header
13. Gas lines
14. Storage tank
15. Cryogenic system
16. Crane
17. Containment shell
18. Steam generators
19. Hot helium supply header
20. Cold helium return header
21. Very-high-pressure turbine
22. Intermediate-pressure turbines
23. Low-pressure turbines
24. Generator
25. Steam lines
26. Cooling towers





ium into a so-called plasma. To most people, the term plasma means the pale liquid sluiced into the veins of accident victims. But when physicists use the word, they mean something entirely different: a substance so hot that it literally tears itself apart, leaving a frantic swirl of energy-packed particles. Only recently have physicists recognized plasma for what it really is: a fourth state of matter (like solid, liquid and gas) which occurs only at ultrahigh temperatures.

Because the Earth is a relatively cool place, plasma doesn't occur naturally on our planet—except in the immediate vicinity of a lightning bolt or other strong electric flash, where the temperature is very high. But it's plentiful elsewhere in the universe. Some estimates claim that 99 percent of all matter in existence is plasma. The stars are made of it.

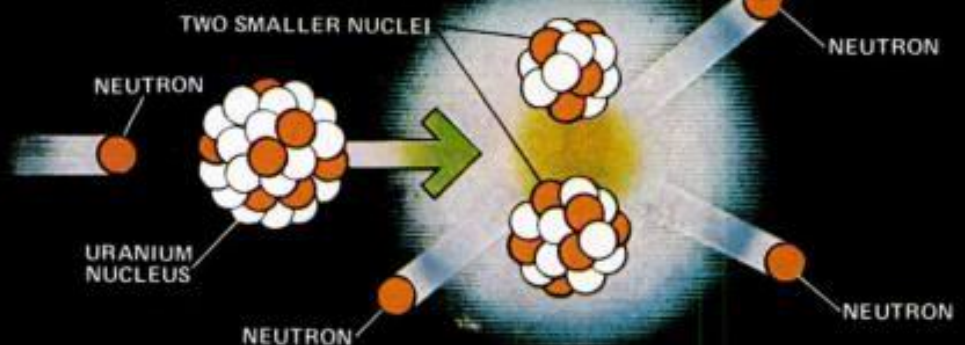
Like our own sun, they are huge plasma balls, superhot gas hopped up with energy, radiating light, heat and radiowaves into the far reaches of the cosmos. Plasma is therefore the prime energy source in the universe. And now, for the first time, mankind is attempting to tap its energy potential directly.

Overwhelming size

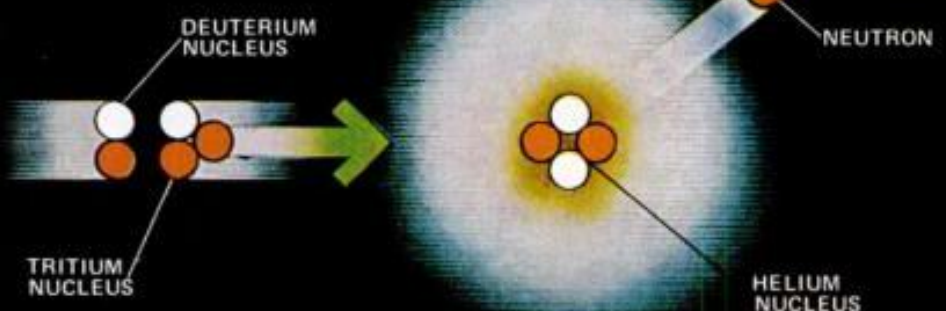
At first glance, the Tokamak overwhelms you by its sheer size. With

Art: Adolph Brotman

ATOMIC FISSION



ATOMIC FUSION

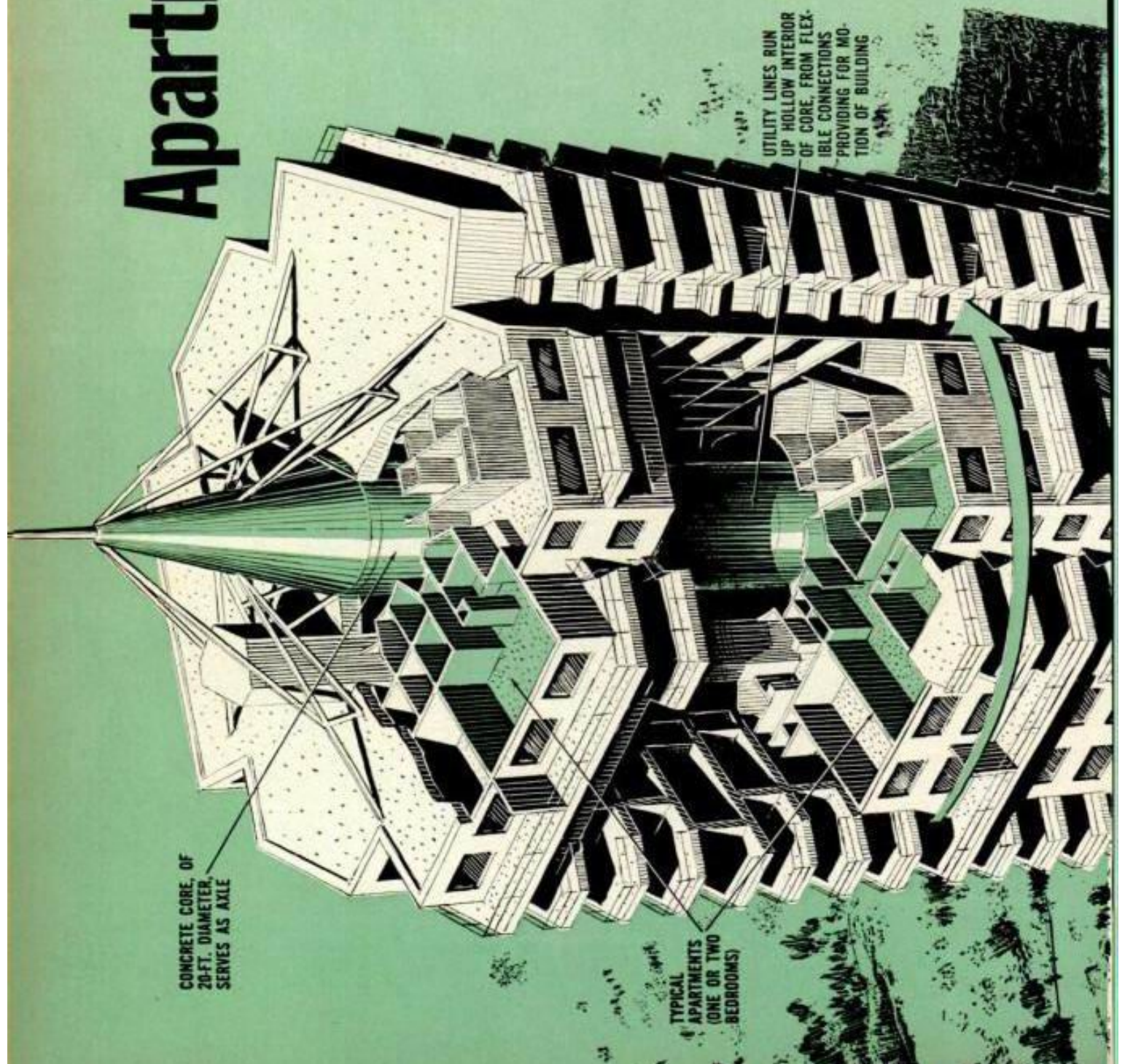


In a fission reaction, the uranium nucleus is split. In fusion, tritium and deuterium fuse to form helium. Both release big amounts of energy.

Apartment House Rotates to Change the View

SEA, shoreline, and mountains will parade before the windows of a revolving apartment house planned for La Jolla, Calif. To give occupants the changing view, the whole building will turn around once in three hours—and then, back again.

An electric motor of only 10 hp. will suffice to rotate the 21,000,000-pound structure. Through newly invented gearing (so far undisclosed but shown schematically), it will turn the building's supporting core—a hollow "axle" of concrete extending downward to hydraulic bear-



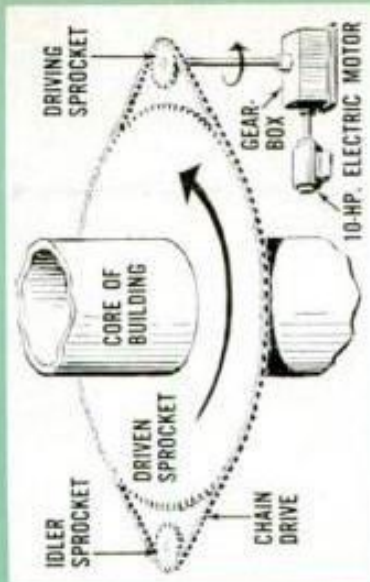
CONCRETE CORE, OF
20-FT. DIAMETER,
SERVES AS AXLE

TYPICAL
APARTMENTS
(ONE OR TWO
BEDROOMS)

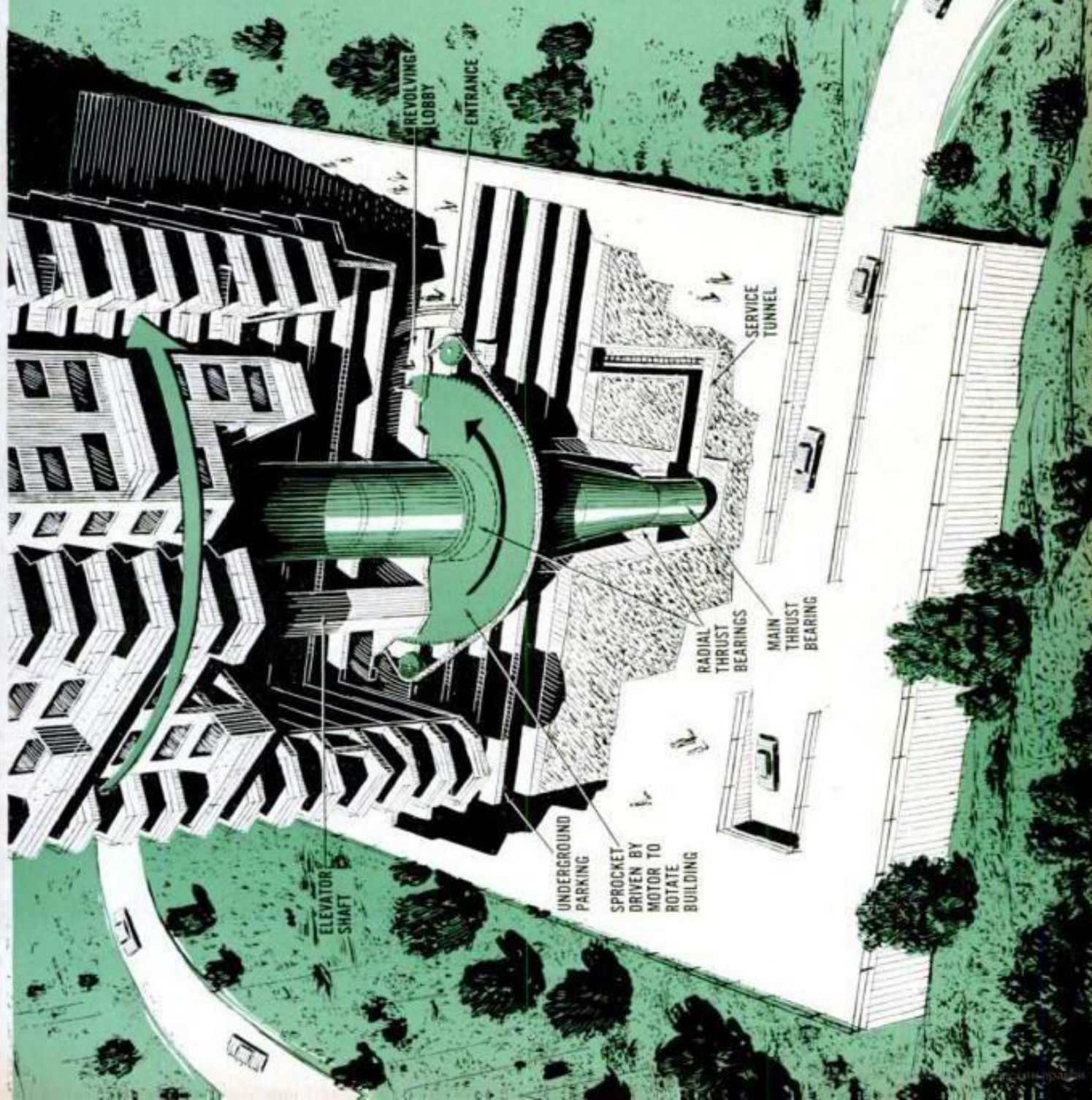
UTILITY LINES RUN
UP HOLLOW INTERIOR
OF CORE, FROM FLEX-
IBLE CONNECTIONS
PROVIDING FOR MO-
TION OF BUILDING

ings 50 feet underground. Depending on whether steel or concrete framing is chosen, the 18 to 24 floors either will be hung from roof girders, or will individually cantilever outward from the core. The mobile apartment house's San Diego architects, Paderewski, Dean & Associates, call it the first of a group of six to rise ultimately on a 30-acre site atop Mt. Soledad, the highest point in the San Diego area.

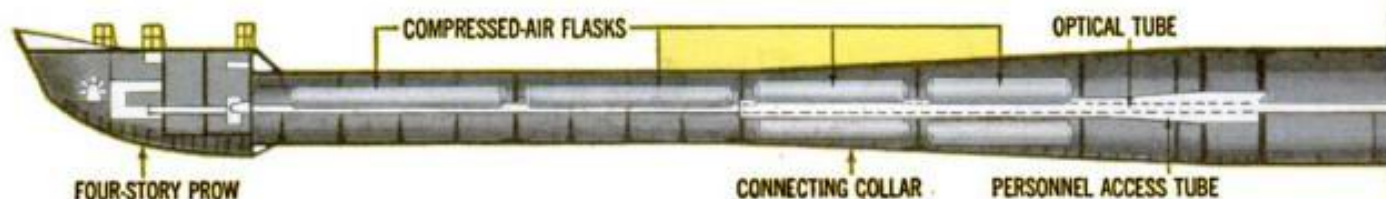
—John J. Fry



Schematic drawing shows how geared-down electric motor will turn the core to rotate entire building pictured in large view.

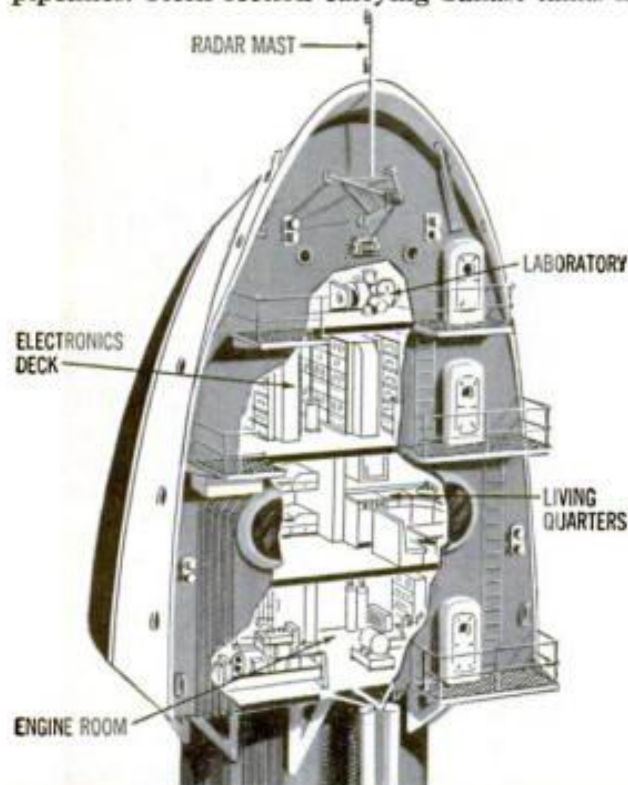


On even keel and under tow, Flip looks almost like a normal ship; then she floods her stern to study the ocean 300 feet down



Long tubular hull looks like two huge welded pipelines. Stern section carrying ballast tanks is

150 feet long and 20 feet in diameter. It's connected to prow by a 12½-foot tube.

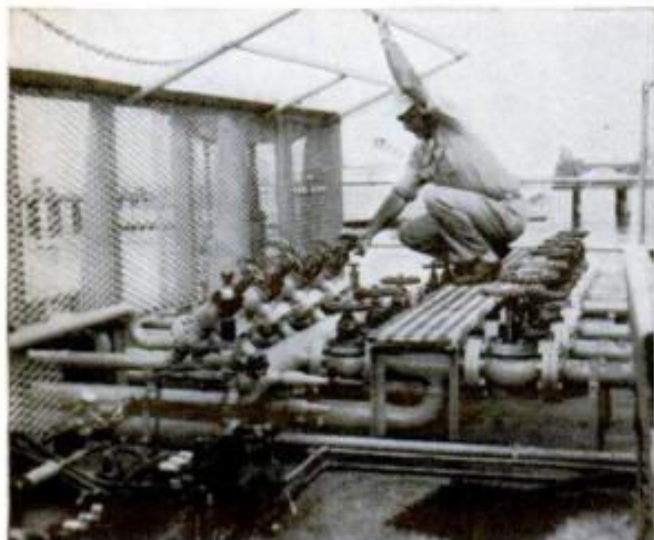


Cutaway drawing shows interior of four-story cabins. Generators on gimbals remain level.

having like a proper boat, however, it isn't at all proper below deck. It's like a house tipped on its side. Many a fixture that should be horizontal is vertical.

This is "Flip." And flip it does. And so would you if you came across it at sea when it's on duty, as it is expected to be this month. For the chief purpose of Flip, a remarkable and important new scientific vessel, is to stand on its rear end, with 300 of its 355 feet submerged. In that position, it has the deepest draft of any craft in the world. It'll ride the waves like a sedate buoy, so stably that it will rise and fall less than three feet in a 30-foot swell. And then, at last, everything inside will be right side up.

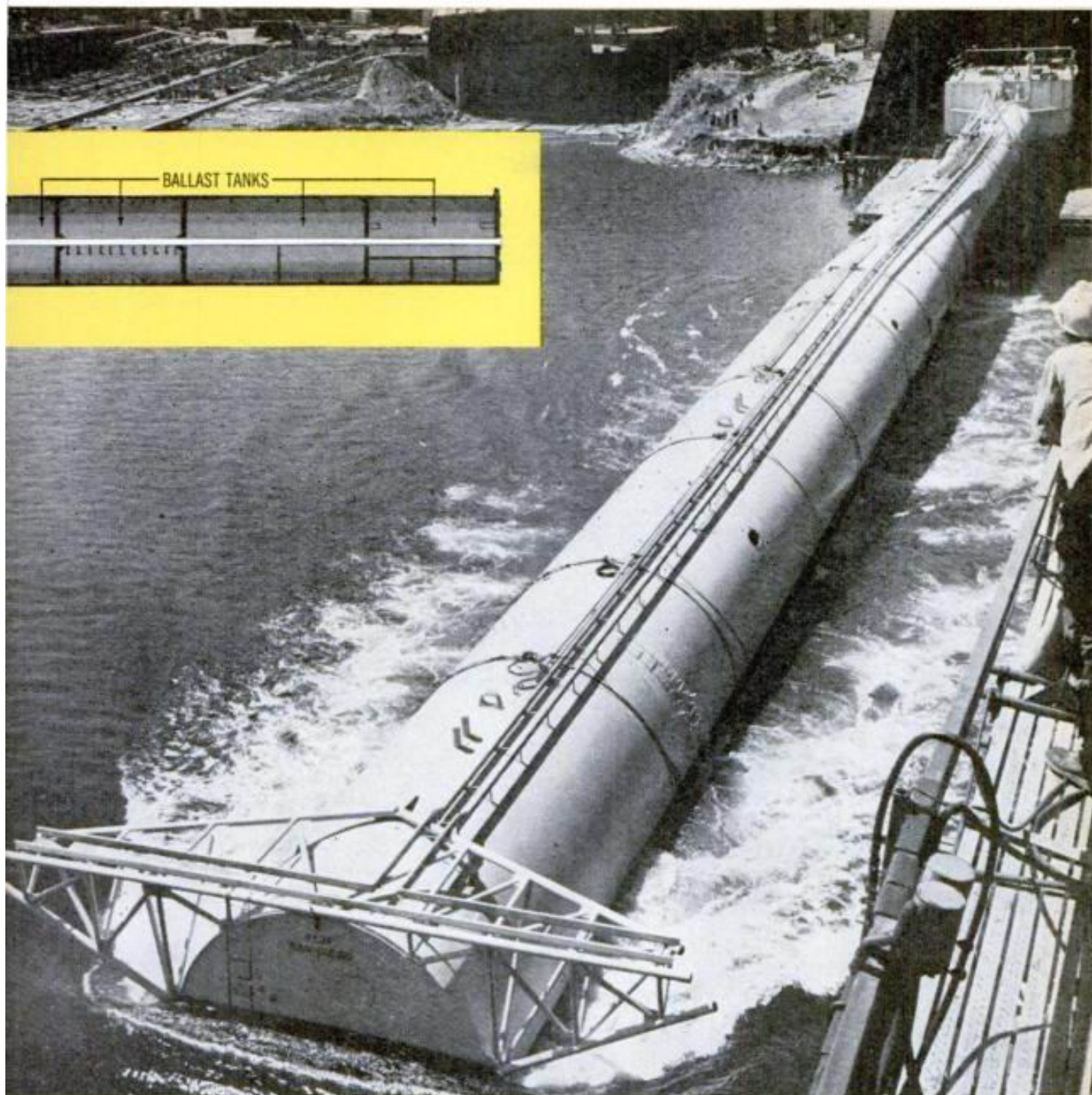
Flip gets its name from FLoating Instrument Platform, which is what it is. It's loaded with electronic gear—hydrophones, radar, microwave apparatus, ra-



Control platform (horizontal view) contains maze of pipes and valves for flooding tanks.



In process of flipping, ship sticks prow up out of water as stern ballast tanks are flooded.



Outrigger at stern is 50-foot hydrophone that will listen for sounds 300 feet below surface.

dio, tape recorders, oscilloscopes—and it belongs to the U. S. Navy. The University of California's Marine Physical Laboratory will operate it for the Navy.

This grotesque vessel's first mission has the highest priority. It is to study the behavior of sound waves underneath the Pacific. Later it will investigate wave motion, inner waves, and marine biology.

Submarine attack is one of the sharpest menaces this nation would face in wartime. Antisubmarine forces need to be able to detect, identify, and pinpoint

sources of sound underwater. Unfortunately for them, layers of ocean vary in saltiness and temperature, direction and speed. All these factors play hob with sound waves. By finding out more about sound waves, the four scientists who will bob up and down on Flip may help give our antisub forces keener ears.

I went aboard Flip at San Diego, where she had been towed from her builder's berth at Portland, Ore. Only her low prow was visible at first from the wharf.

[Continued on page 178]

The Ship That's Built to Sink

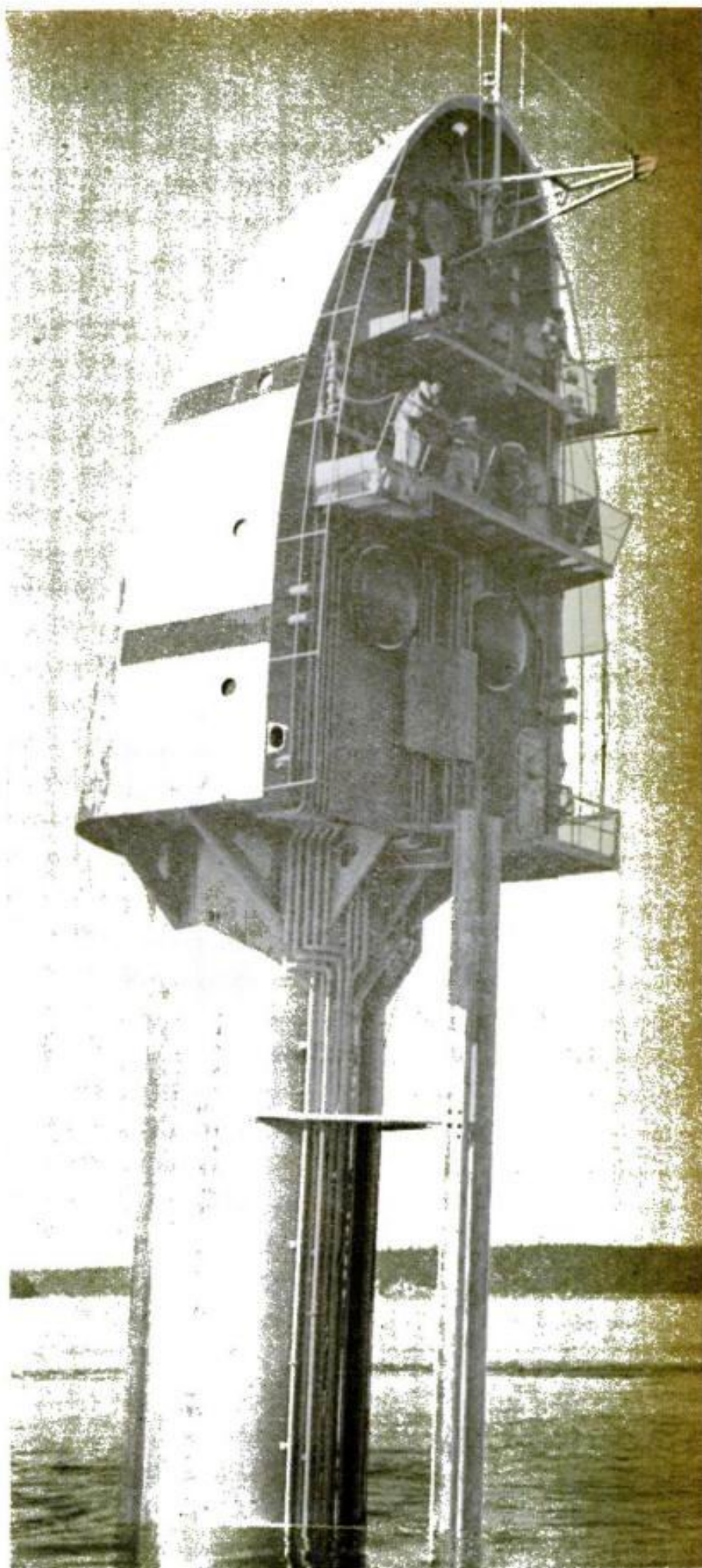
Flip is its name, and flip it does—to work standing upright on its tail

By Wesley S. Griswold

IT'S the craziest-looking vessel I ever did see. You couldn't really call it a ship—though it will travel thousands of miles at sea. It has a fairly orthodox (though rounded) prow—but its hull is a huge steel tube. It's 355 feet long and weighs 600 tons—but it can't budge itself. It has to be towed wherever it goes. It isn't a barge, though.

If you could set it on its blunt, circular stern on land, it would stand as tall as a 35-story building. Viewed from above when it is lying full length in the water, like a proper boat, it resembles an immense stalk of asparagus, painted gray.

CONTINUED



Fantastic new rescue craft—the DSRV..



The Deep Submergence Rescue Vehicle picks up crewmen—24 at a time—from nuclear submarine lying helpless on ocean floor. (DSRV will operate at an incredible 3,500 feet below surface.) Inner pressure hull consists of three interconnecting 7½-foot spheres. One for three-man crew; others contain breathing masks for emergency oxygen supply, house 12 rescued submariners each. Transfer from distressed sub to DSRV is through bell-shaped hatch.

omises lost submariners...

ESCAPE FROM THE DEEP

olution to number-one underwater problem:
DSRV can be flown anywhere, dive hundreds
of fathoms, to find and evacuate stranded subs

by CMDR. SCOTT CARPENTER, USN (RET.)



Somewhere in the dim recesses of the sea, a U.S. Navy nuclear submarine on patrol eavesdrops on the sounds of the deep. Her many sensors detect a whole spectrum of underwater activity, so that the men on board are more aware of their watery environment than even the denizens of the deep.

Nevertheless, this machine and the men inside are out of their element—and vulnerable. Accidents happen, despite careful equipment design and rigorous training. What if the sub can't surface?

The answer is the Navy's Deep Submergence Rescue Vehicle—DSRV for short—

now abuilding at the Lockheed Sunnyvale plant in California. The 50,000-pound, 44-foot torpedo-shaped craft has a three-sphere steel inner pressure hull that will withstand depths of more than 3,500 feet. Using space-age technology, the DSRV makes deep-ocean submarine rescue a reality at long last.

Suppose an accident disables our patrolling submarine. She settles helplessly to the uneven, slanting bottom. All attempts to regain control are unsuccessful. Lying on the bottom, she and all her men would have been forever committed to the deep—before DSRV.

Continued

POPULAR SCIENCE salutes Cmdr. Carpenter with a hearty "Welcome Aboard!"

We are delighted and honored to announce that Scott Carpenter has agreed to write regularly for this magazine on inner space—the fascinating world under the seas.

Commander Carpenter, of course, is world-renowned as both astronaut and aquanaut. He is, in fact, the only man to have both orbited our planet and dwelt on the ocean floor!

In 1959, after ten years as a Navy flyer, he became one of the original seven U.S. astronauts. In 1962, he flew three times around the

earth in the second U.S. manned orbital flight.

In 1965, he joined the Navy's Man-in-the-Sea program. As a Sealab II aquanaut, he led two teams that lived and worked for 30 days 205 feet under the Pacific.

A two-year return stint with NASA followed. From 1967 until his recent retirement he was Assistant for Aquanaut Operations in the Navy's Deep Submergence Systems Project.

Welcome to Scott Carpenter—astronaut, aquanaut, and now author.

—ERNEST V. HEYN, Editor-in-Chief

Deepest-diving rescue sub can navigate to within one inch

Now, however, the lost sub's "Mayday" distress message—sent by a radio buoy floated to the surface—triggers a rescue-mission system that will bring relief within 24 hours.

At a naval installation, a DSRV and her support equipment are lifted onto special transport vehicles, which rush them to a nearby airfield. There, the DSRV is loaded on one giant C-141 Starlifter jet, the support equipment and transport vehicles aboard another. All are flown to the port nearest the stranded sub. Simultaneously, a nuclear sub is directed to the same port. Enroute, she prepares for the rescue task—she will become the "mother" submarine.

Rendezvous for rescue. Within hours, the DSRV makes rendezvous with the

mother sub. The DSRV is mated to the much larger sub's after hatch, for it will be carried "piggyback" underwater to the accident site. Not heavy pack ice nor even hurricane conditions on the surface will impede the operation once the mother submarine finds the deep ocean. She can then cruise waters perpetually serene.

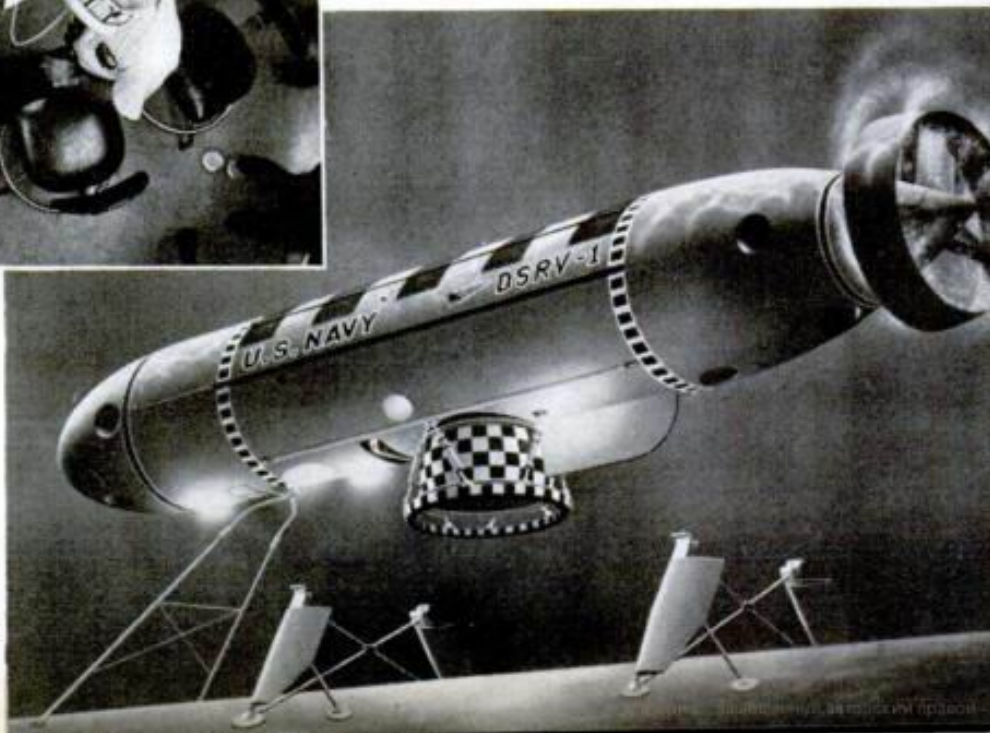
But here is where the real work begins. To locate a sunken object, even one the size of a large modern nuclear submarine, is no easy task. Precise navigation brings the duo to the search area, then the backpacking mother sub begins a search pattern. Accurate plotting and careful listening guide the big sub to her stricken sister. Her sonar gear, communications equipment, and other special rescue devices tell the sub's skipper and the three-man DSRV crew that all is well with the trapped crew, but that slow flooding is driving the internal pressure of their vessel slowly upward. There is just time.

DSRV is on its own. Now the mother sub comes to a hover. The DSRV hydronauts are briefed and transfer to the rescue vehicle, which is then sealed off and detached. Down it dives, seeking the escape hatch of the stranded sub.

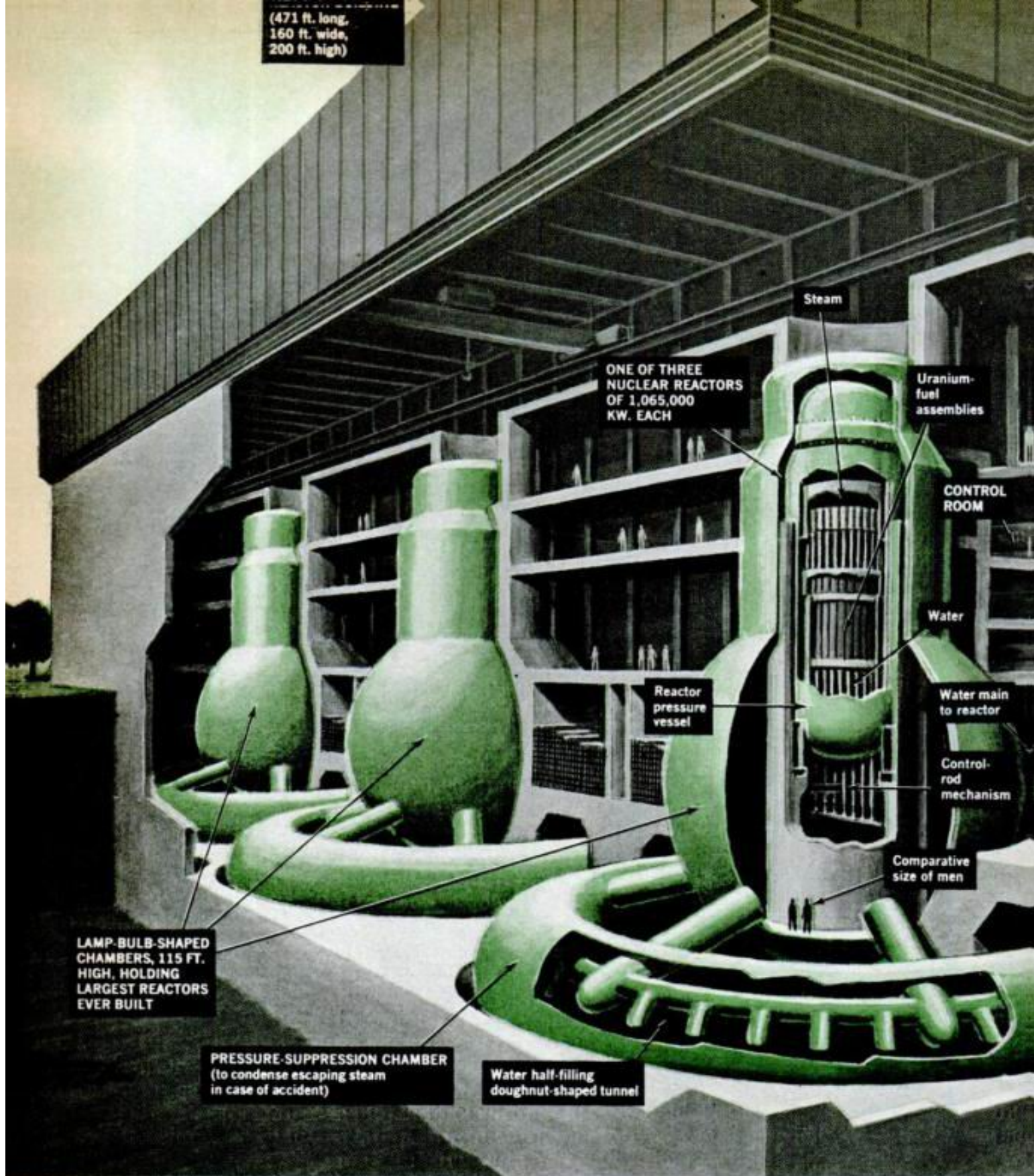
During this crucial maneuver, the DSRV uses the most elaborate array of navigation and sensing equipment yet carried beneath the sea. Her computerized inertial-guidance control system, with gyros and accelerometers, is actually more flexible than Apollo's. Forward-searching horizontal and vertical sonars locate un-



Emergency breathing unit shown in test above can provide clean air for 13. Aboard DSRV, each rescue sphere has one such unit, supplying total of 24 rescued submariners. DSRV goes underwater to accident site "piggyback" on nuclear mother sub (right). DSRV needs complex control system to berth on mother.



(471 ft. long,
160 ft. wide,
200 ft. high)

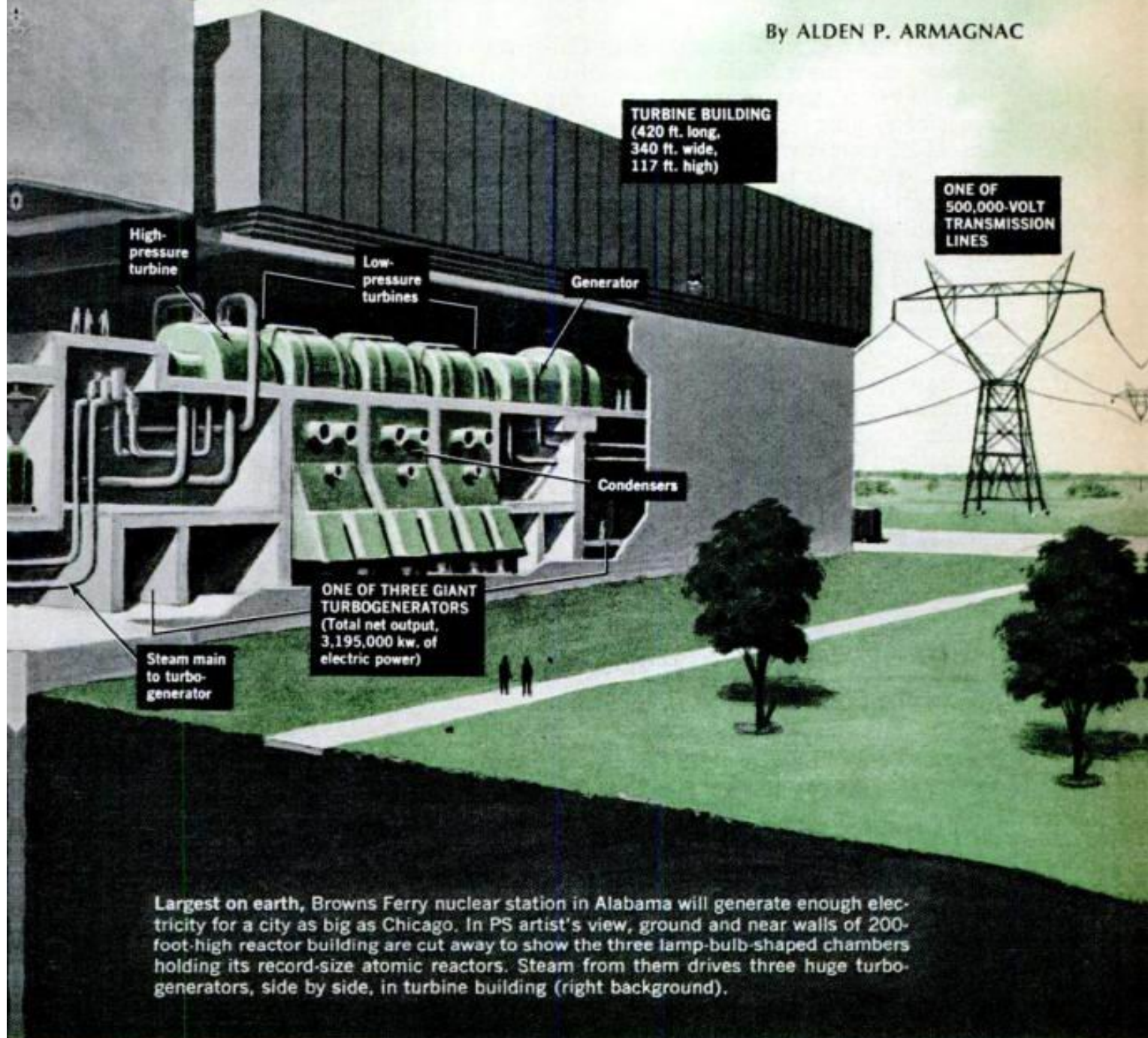


A 3,195,000-kilowatt nuclear project in Alabama dwarfs the largest U.S. electric station of any kind today—and highlights an A-plant boom that will cut your electric rate and reduce air pollution

ILLUSTRATIONS BY RAY PIOCH

World's Biggest Atom-Power Plant

By ALDEN P. ARMAGNAC



Largest on earth, Browns Ferry nuclear station in Alabama will generate enough electricity for a city as big as Chicago. In PS artist's view, ground and near walls of 200-foot-high reactor building are cut away to show the three lamp-bulb-shaped chambers holding its record-size atomic reactors. Steam from them drives three huge turbo-generators, side by side, in turbine building (right background).

Beside the Tennessee River in northern Alabama, 30 miles west of the famed Marshall Space Flight Center at Huntsville, the Tennessee Valley Authority is building a fabulous \$392-million atomic-power station. Its new Browns Ferry Nuclear Plant will be the mightiest atomic

generating project in the world—and will dwarf the biggest electric plant, of any kind, in this country today.

Currently our largest power station is the great 2,190,000-kilowatt U.S. hydro plant at Niagara. Soon it will be topped

Continued



Trabant engine in nose of the Rotoped drives a blower that feeds compressed air via tubular

bump, it just stops turning, then starts driving again as soon as it hits the ground.

Bypassing friction. Run by compressed air, the self-propelled wheel has many other advantages. The usual mechanical transmission is completely eliminated, together with its bulk, weight, and frictional losses. All-wheel drive is easy, differential action is automatic, and all wheels can be steered for exceptional maneuverability. Rolling resistance is very small, and ground pressure is low, due to the large contact area.

Inventor Julius Mackerle, a senior engineer at the Research Institute, sees the

machine as an ideal cross-country vehicle. It can move on any kind of terrain, and with further development could climb grades like a horse. And the more wheels the greater the edge over a conventional all-drive multiwheel truck, because of the large number of power-robbing gears and universal joints in the drive-train of a conventional 6 x 6 or 8 x 8.

The wheel—a simple idea. Mackerle studied the movements of a walking man, who first stands on one foot, then leans forward onto his second outstretched leg to make a step. What limits his efficiency and speed is the need to accelerate the first

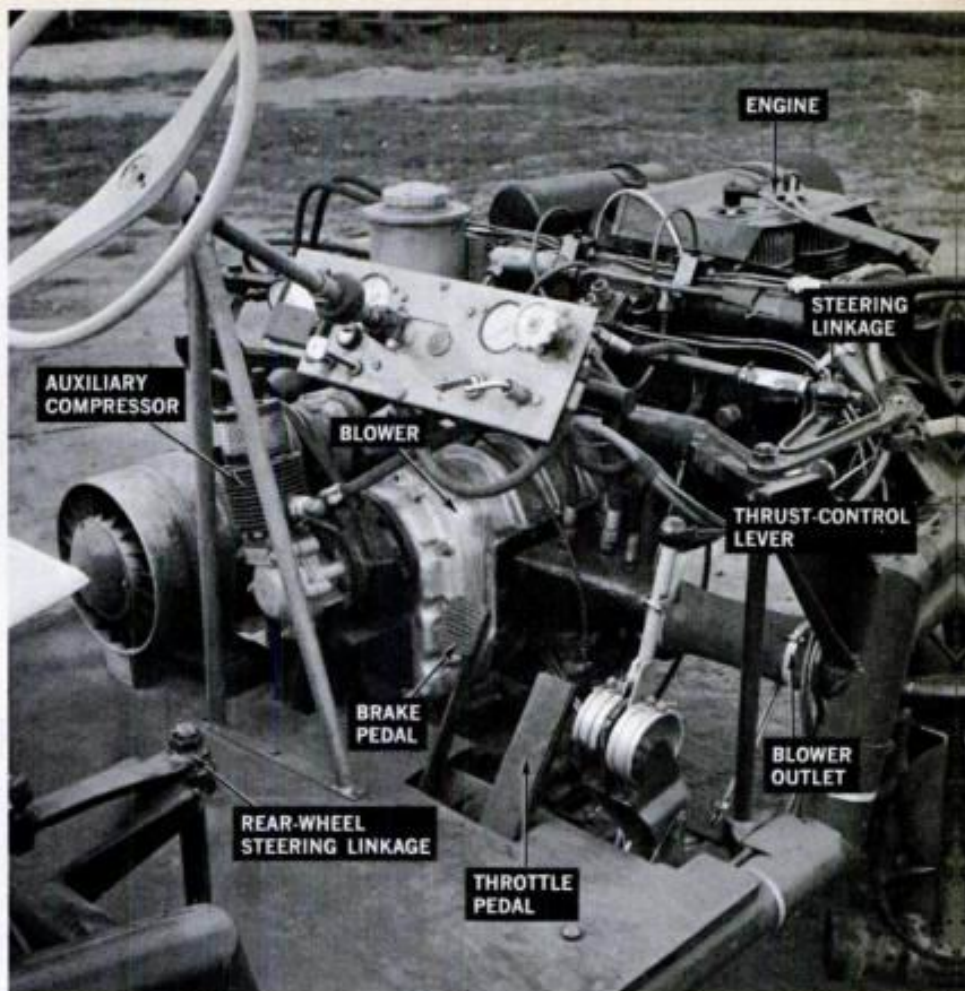


frame members to the rig's wheels.

foot forward from rest through the distance of two paces for the next step. The counterweight effect of the leg swinging against the direction of travel tends to oppose the body's forward movement.

Mackerle simulates the action of a thrusting leg with an inflatable rubber bag, and uses a ring of these around the wheel circumference in place of a regular tire. Compressed air is piped through the hollow axle to a rotary valve in the wheel hub that feeds it to

[\[Continued on page 192\]](#)



All driving machinery is crammed into the front of the chassis. The controls are no more complicated than those in a modern car, but the Rotoped's off-road mobility may be unequalled.



The inventor of the Rotoped — Julius Mackerle — checks on a cable connection to a wheel hub. When the vehicle is at a standstill, the bags in contact with the ground are partially deflated.

The Incredible No-Torque "Walking" Machine

It can turn on its axis, "walk" sideways, and tackle the roughest terrain and unbelievable gradients

By DAVID SCOTT / PS European Editor

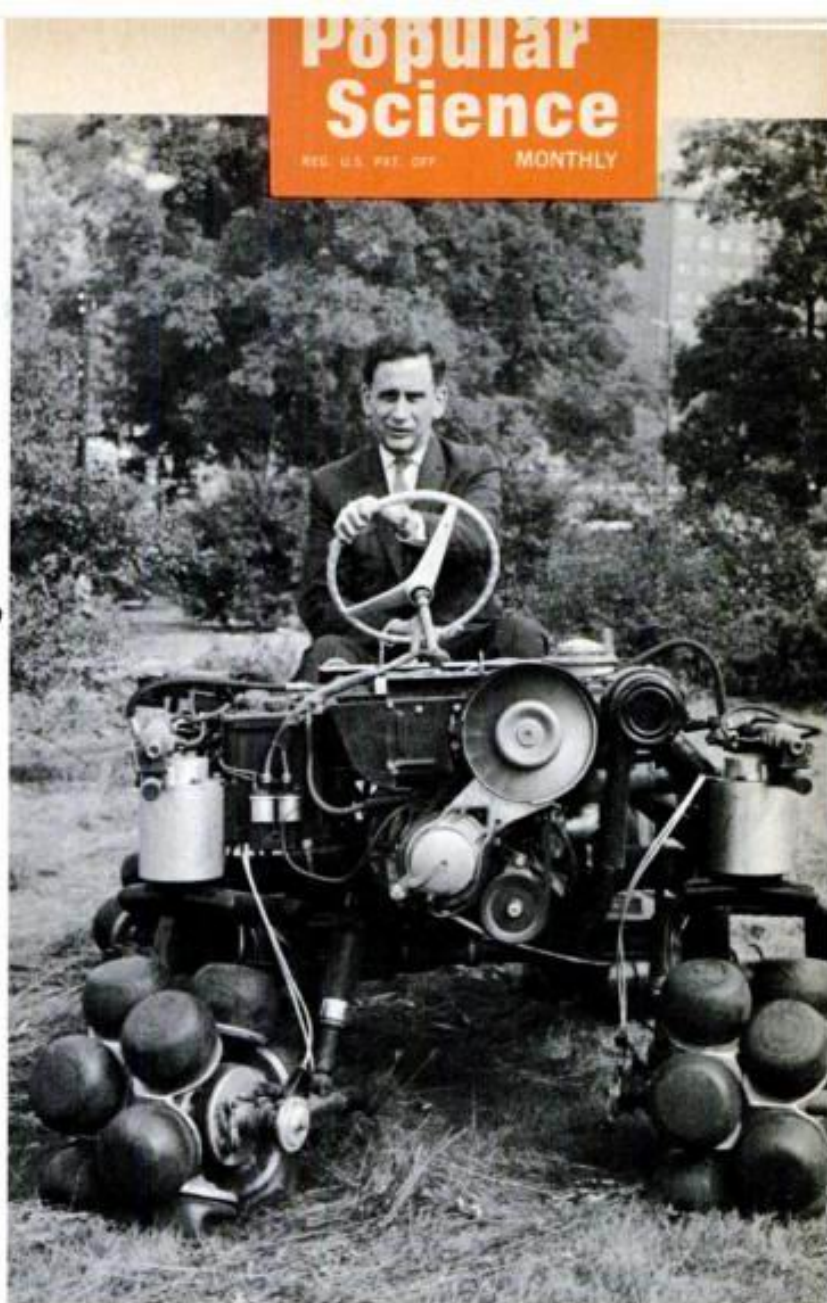
The zaniest ride I've ever had was at the wheel of this weird walking-wheel vehicle on a grassy hillside in a Prague suburb. What's it like? Something like driving over rough cobblestones, but with a trembling waddle rather than a jiggling over the bumps. Though the ride is pretty smooth the clatter of tortured rubber sounds like you're rolling on four flat tires.

Stamp hard on the gas and there's a banshee howl from up front, but acceleration is slow a-comin'. A yank on a lever and suddenly it's full-speed astern. Twist the steering wheel to full lock and you're circling around on your own axis.

Developed at Czechoslovakia's Motor Car Research Institute from an 18-inch-long model built to prove the principle (PS, July '64), the seven-foot Rotoped has wheels that rely on gravity rather than friction for traction.

As no torque is applied to them, they won't spin or dig in on sand, mud, or ice. If one bounces off the surface on a

Continued



Maneuvering the Rotoped is easy, Scott found, after a quick briefing on the controls. All four wheels are steered by individual hydraulic rams at each corner.

Here's how the wheels are angled to make the Rotoped spin around its axis. Cables controlling air valves can be reset to give sideways motion.



The Spaceplane That Can Put YOU in Orbit

You won't need a "contour couch"
or an astronaut's training to ride
comfortably into space in NASA's
shuttle craft (late-1970s model)

By **DR. WERNHER von BRAUN**

NASA Deputy Associate Administrator

PS Consulting Editor on Space

ILLUSTRATIONS BY BOB McCALL

Toward the end of the Seventies you will no longer have to go through grueling years of astronaut training if you want to go into orbit. A reusable space shuttle will take you up there in the comfort of an airliner.

Just as in a commercial jet, professional flying will be required only in the cockpit. In the rear, it will be "coffee, tea, or milk," but you may have to share the accommodations with some high-priority cargo or laboratory equipment.

Shuttle to be reusable. Unlike the expendable launch vehicles and the non-reusable spacecraft of the Mercury, Gemini, and Apollo brand, the space shuttle of the late Seventies will return to the launching site and, after careful checkout, refurbishment, and refueling, can be used over and over again, hopefully a hundred times or more. This will permit significant reductions in the cost of future space operations: Today it still costs between \$500 and \$1,000 to orbit one pound of payload. With the shuttle, costs are expected to drop to about \$50 a pound.

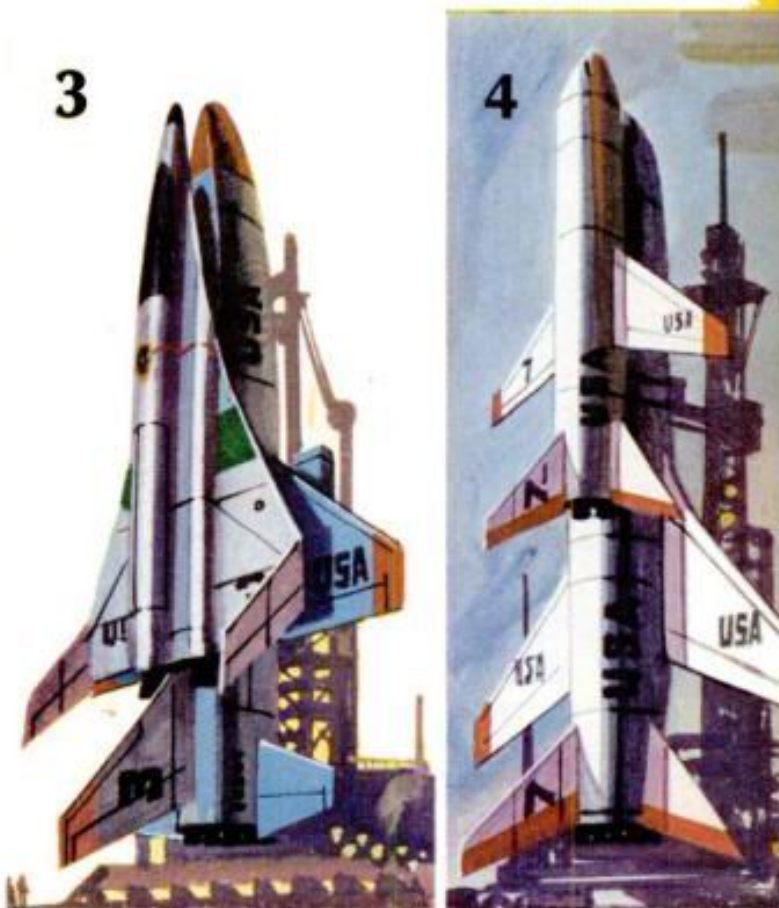
These savings in hauling costs are by no means the only advantages offered by the shuttle. The craft's benign flight environment—moderate accelerations, low noise levels, shirt-sleeve operations throughout the entire flight—will enable scientists and technicians without aviation training to ride it. Moreover, it will permit, at least in some flight missions, the use of normal laboratory equipment and instrumentation in space. This is of great significance; while the sophisticated equipment of some of our present unmanned spacecraft costs as much as \$10,000 to \$30,000 per pound, some commercial laboratory equipment and instrumentation can be had for about one percent of that cost.

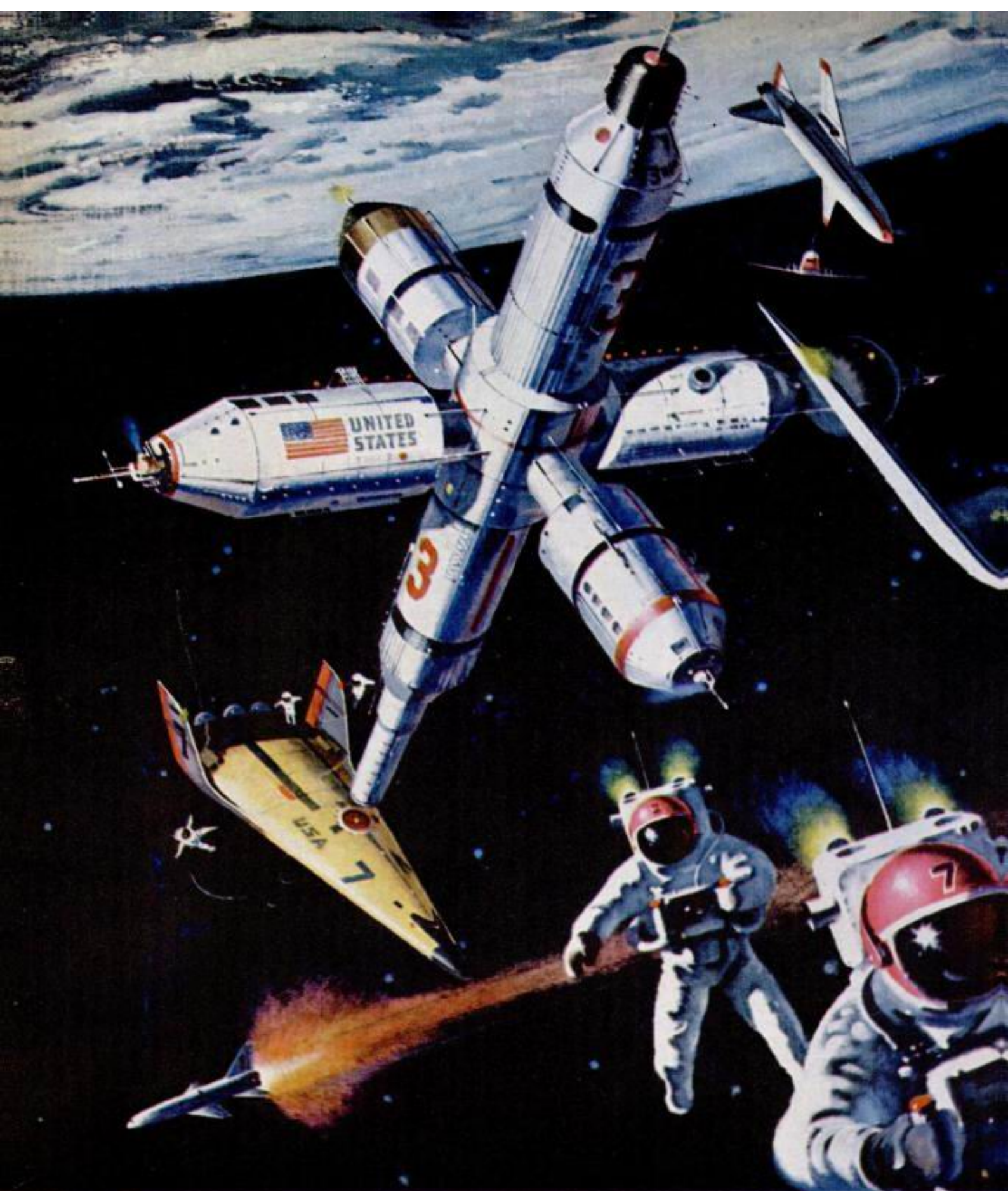
It would be ideal, of course, if we could build a single-



Four Space-Shuttle Concepts

Here are examples of tentative designs for a space shuttle, made public by members of the four industrial teams competing in the project: 1. McDonnell Douglas/Martin Marietta. 2. Boeing/Lockheed. 3. North American Rockwell/General Dynamics. 4. Grumman Aerospace. Each of the pictured space-shuttle versions is a composite craft consisting of two stages, a booster and an orbiter, and is launched vertically like a space rocket, as shown. Its two stages separate in space, and both return to earth for re-use.





Artist's conception of space shuttles in action shows passenger shuttle about to dock at future space base, left, orbiting earth (top)

stage-to-orbit shuttle which, without shedding any boost rockets or tanks, could fly directly up to orbit and return in one piece to the takeoff site for another flight. Although we may well know how to build such a vehicle some day, most studies unfortunately show that with the present

state of propulsion and structural technology this objective would be just a shade too ambitious. A single-stage-to-orbit vehicle, by definition, must be capable of carrying its entire dry weight, plus return fuel, crew, passengers, and cargo into orbit; and its own dry weight makes up



left). Utility shuttle, right, retrieves out-of-order earth satellite for repair in orbit. Spacemen with self-propulsion gear aid operations.

the major part of this load. A minor overshoot in its projected structural weight, or a loss of as little as one percent in rocket-engine performance, could therefore wash out the entire payload! Technological advances will undoubtedly improve the successful chances for such

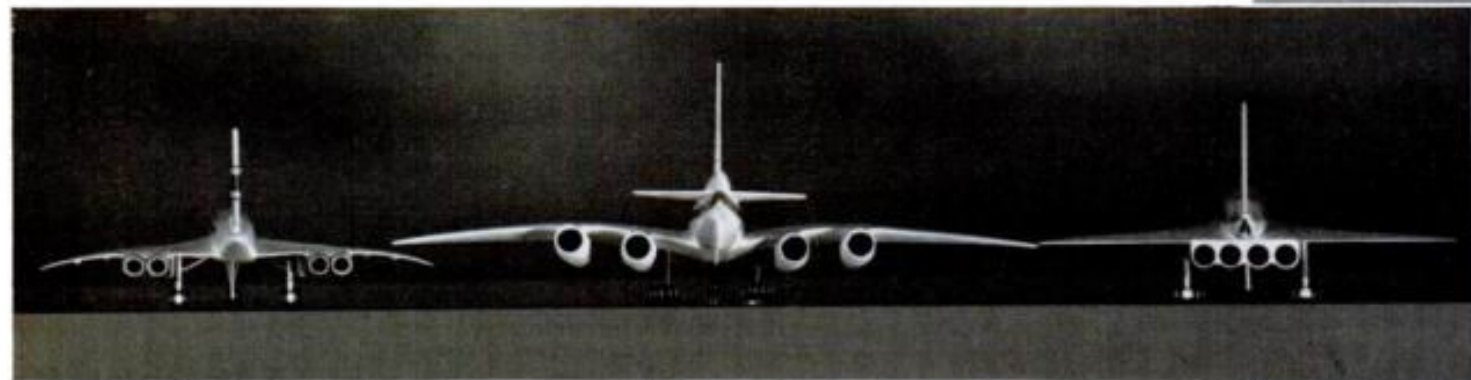
a single-stage shuttle design, but at the present time, few aerospace contractors are willing to take the gamble.

The shuttle concept NASA considers most attractive at this time is a two-stage, vertical-takeoff vehicle, with

[Continued on page 104]

Your First Ride in an SST— Sooner Than You Think

It might not be an American-made plane, for airlines may soon be buying French or even Russian SSTs to carry you through the sound barrier



Views of SSTs above and at right give comparative sizes of three designs. Rear view of American SST (above, center) shows largest wingspan—143 feet;

tallest tail—52 feet. View at right reveals Boeing's great length—298 feet. Tu-144, shortest, will be 188.5 feet long; the Concorde will be 193 feet long.

By **BEN KOCIVAR**
PS Consulting Editor, Flying

You've heard some wishful thinking and wild hollering for and against the supersonic transport. If you're confused, don't be embarrassed—you are in good company. Pilots, airline presidents, engineers, congressional and government leaders, ecologists, and the paying public can be found on both sides of the argument.

In any case, at least three SSTs are coming—the Concorde, built by a French/British team; the Russian-built Tupolev Tu-144; and the Boeing 2707-300. Furthermore, there is an even chance that you'll be able to buy your first SST ride in 1973.

It's going to be a thrill—although it won't *feel* so very different from flying today's fast airliners. I flew at twice the speed of sound in a Lockheed two-seater trainer and there's no physical sensation when going through the sound barrier—simply because it is no longer a barrier. But there is quite a mental boost when you read the dials and see Mach 1 (the speed of sound) and then Mach 2 indicated. When you look out from an altitude of more than 50,000 feet, the sky is not only incredibly blue, but you can actually see the horizon curve in the distance.

The French/British team already has two Concorde flying. The Russians have at least one Tu-144 in the air. The first American SST flight,

though, will not occur until the end of 1972, possibly later.

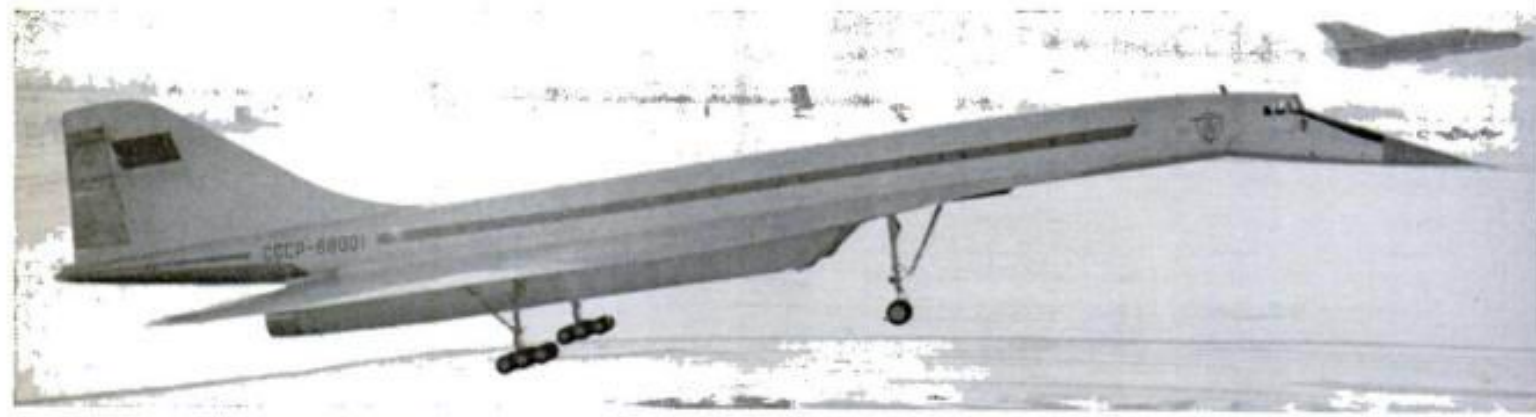
Vive la difference. The present designs show basic differences:

- The Boeing 2707-300 will weigh 750,000 pounds on takeoff, carry 298 passengers, and cruise at almost 1,800 mph.

- The Concorde will weigh 385,000 pounds, carry 128 passengers, and cruise at 1,350 mph.

- The Tu-144 will weigh 330,000 pounds, carry 120 passengers, and cruise at 1,550 mph.

To protect it from air friction at its higher speeds, the U.S. craft will be made of titanium. The other two will be made mostly of aluminum. All have four engines under the wing and are designed to have a range of 4,000



Tu-144 comes in for landing after a test flight. The supersonic Russian passenger

plane was first SST actually to fly, and may be first to fly heavily traveled transatlantic.

It has already flown at more than 1,200 mph, and as high as 50,000 feet, in tests.



statute miles, enough for transatlantic crossings.

The price tag on an SST runs high: an estimated \$40 million in 1967 dollars for the U.S. model, and \$20 million for the Concorde. Some experts expect inflation to boost the delivered price of the Boeing to almost \$60 million. Cost of the Tu-144 is probably closer to that of the Concorde.

What do we know about the SSTs already flying? To date, no Americans have flown the Tu-144, though they have seen it and been aboard. First shown to Western newsmen at the Moscow airport, it was the first SST to fly (in 1968) and the first to fly supersonically (in June, 1969).

Last year a group of top U.S. experts was invited to see the plane. It included Najeeb Halaby, president of Pan Am and former head of our FAA, and Maynard Pennell, former director of Boeing's supersonic program. They were not permitted to fly it but were given a 90-minute tour of the plane, and also discussed it with designer Andrei Tupolev.

The Americans were told the craft is about 200 mph faster than the Concorde; it will go into service on Russia's internal routes first, and will probably beat the Concorde in service across the Atlantic, flying supersonically to Montreal and then subsonically to New York.

The Tu-144. It will have two cabins—one first class, for 18 passengers; the

other tourist class, for 80. First class can be converted to carry 40 tourist seats or, for summer flights of under two hours, the plane can handle 135 passengers.

The Tu-144 will carry two pilots and a flight engineer. Like the Concorde and Boeing, the nose section is depressed for better visibility on take-off and landing.

Control systems are rigid, with hydraulic boosts, and all hydraulic systems are duplicated. Instruments correspond to international naviga-

tion and landing requirements. The craft uses some titanium at leading-edge points that are subject to aerodynamic heating.

U.S. engineers are puzzled by Russian use of two closely spaced nacelles for the four engines, which leaves a high-drag slot between them. Other Russian designs show they know better. The turbojets are Kuznetsov NK144s, each with over 38,000 pounds thrust. The air intakes automatically adjust to flight conditions and the nozzles are also adjustable. Each en-



Concorde soars aloft at steep angle. Plane above is the first of two built so far by the French/British coalition that is de-

veloping the Concorde. It flew at a speed of Mach 1.53 and as high as 47,000 feet during its early test program.

FLAIR—The “Way-Out”

Man-made offshore islands could provide needed space for giant, new jetports

By PAUL WAHL

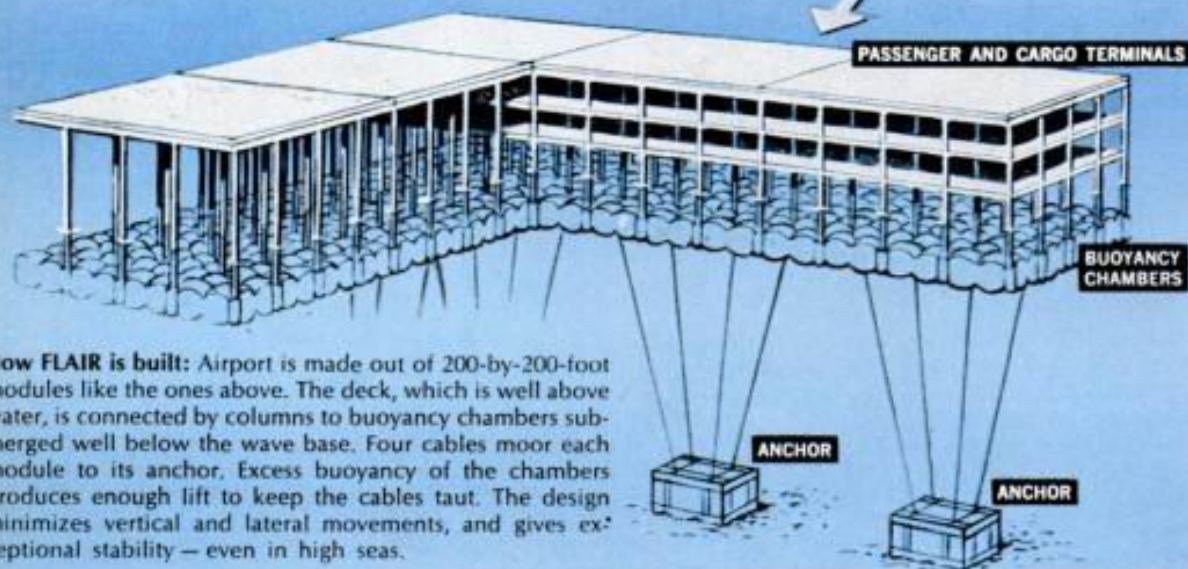
ILLUSTRATIONS BY RAY PIOCH

Before the Seventies are out, the Atlantic Ocean could have a brand-new island: an artificial one of steel and concrete, anchored off the New York coast. It would be called FLAIR—for floating airport.

Although developed to answer the New York metropolitan area's crying need for another jetport, the FLAIR concept might also solve the airport prob-

lems of other cities where offshore location is possible.

Air traffic has outgrown the facilities—even the airspace—at most, if not all, principal U.S. airports. Planes wait interminably to take off or land. There is a real danger of midair collision in the crowded skies. Jet noise and fumes can make life miserable if you live in a nearby residential area.



How FLAIR is built: Airport is made out of 200-by-200-foot modules like the ones above. The deck, which is well above water, is connected by columns to buoyancy chambers submerged well below the wave base. Four cables moor each module to its anchor. Excess buoyancy of the chambers produces enough lift to keep the cables taut. The design minimizes vertical and lateral movements, and gives exceptional stability—even in high seas.

Floating Airport

No wonder nobody wants an airport for a neighbor!

Expansion of existing facilities often isn't practicable. Community opposition is making it increasingly more difficult for airport planners to find suitable land sites for new installations. Additional jetports must be built—but where?

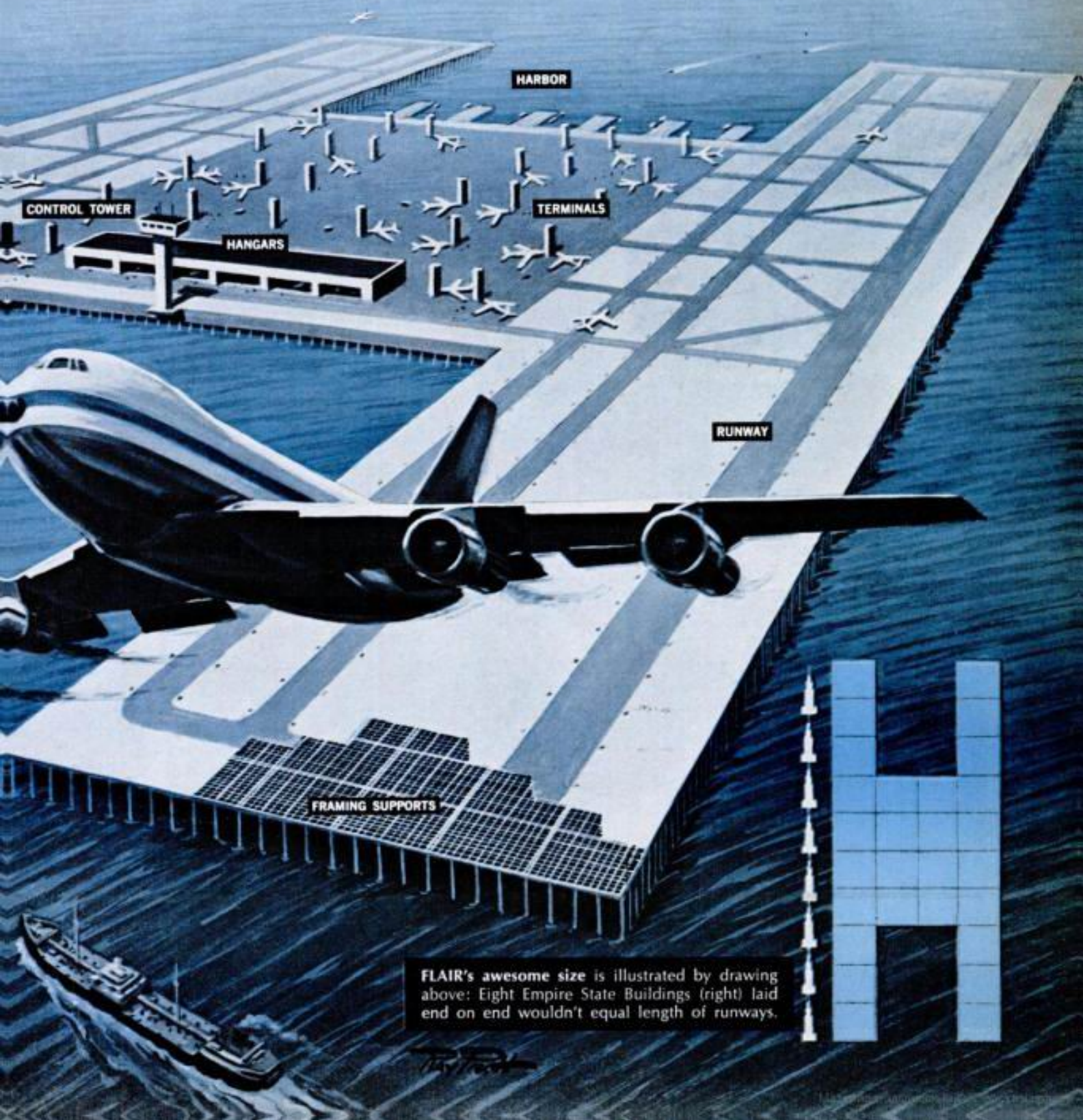
Recently, a revolutionary solution—the floating airport concept—was pro-

posed by the Manhattan-based firm of Paul Weidlinger, Consulting Engineer. This concept is the product of a study by a distinguished team of engineers, including Weidlinger and his associates, Prof. Mario G. Salvadori (of Columbia University School of Engineering and Applied Science) and Istvan Varga. Dr. Richard Garwin, of Columbia's Watson Laboratories, also contributed.

The study suggests placing FLAIR in the Atlantic Ocean, 40 to 50 miles from New York City, within the area of the continental shelf. The location could be selected to avoid interference with surface navigation and existing air-traffic patterns.

The floating airport would be 12,000 feet long and 5,600 wide, with a total

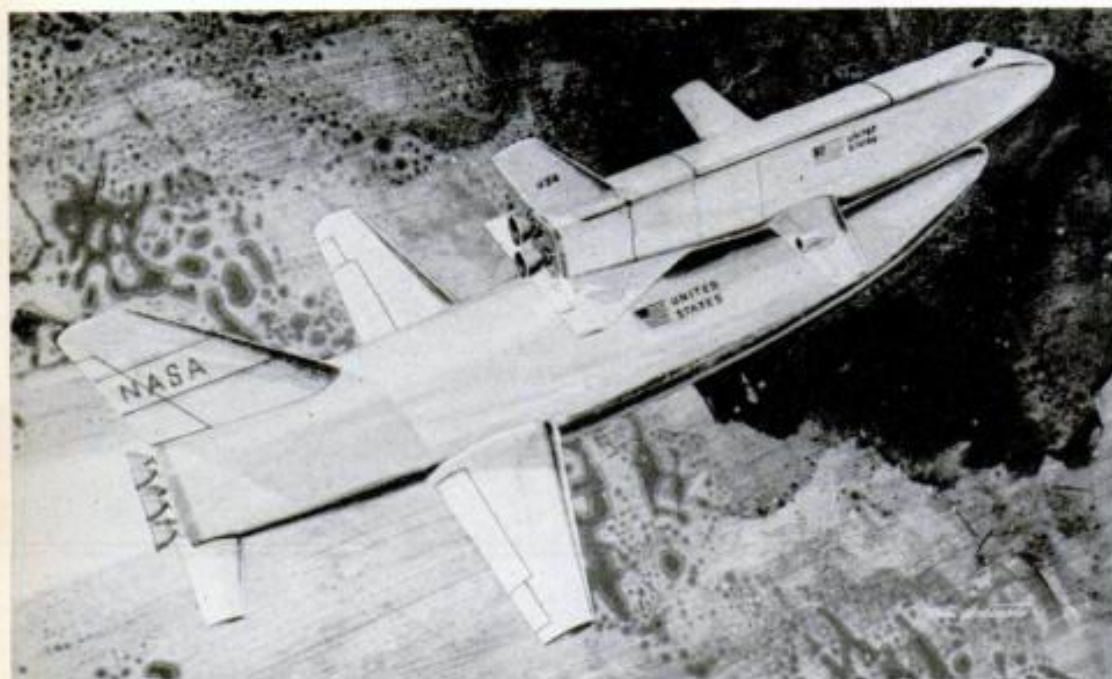
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FLAIR's awesome size is illustrated by drawing above: Eight Empire State Buildings (right) laid end on end wouldn't equal length of runways.

What's New

A PICTURE ROUNDUP OF NEW PRODUCTS AND DEVELOPMENTS



Piggy-back space ride ▲

Re-usable space shuttles are what NASA is looking for these days [PS, July], and here's another competing design by Aerojet-General. It features a large booster and smaller cargo vehicle that take off together in a vertical position, separate in orbit, glide back to earth for re-use.

Bivalve boat ▲

This twin-hulled dinghy, called the Oyster, hinges along its centerline just like its namesake. Afloat, its wooden bench seat locks it open. Ashore, a padlock locks it shut for safe inside storage of your motor and fishing tackle. Marine Supplies and Services, Santa Barbara, Calif.

▲Headlight wipers

Headlights caked with dirt from foul-weather driving? Don't despair. Designers at England's Lucas factory are working on headlight wipers. The ones for these twin rectangular lights work just like windshield wipers. Round lights get a rotary wiper run by flexible cable. Both types include washers.

Three-wheeled wedge ➤

It looks like a cross between a Gremlin and a wedge of cheese, but it's the Bond Bug, a new fun car from England. A 29-hp engine up front drives the rear wheels through a four-speed box. It has no doors—the canopy is front-hinged to tip forward for entry and exit. Fiberglass body is bright orange.



SKYLAB

Our First Space Station



Cutaway view shows Skylab in orbit. Docked to it, in foreground, is Apollo spacecraft that brings and returns its three-man crew.

Here's an advance look at our biggest manned spacecraft yet. In this 83-foot, 68-ton orbiter, due to circle 270 miles above the earth in 1972, successive three-man crews will try living under zero gravity for periods of four to eight weeks

By DR. WERNHER von BRAUN

*NASA Deputy Associate Administrator
 PS Consulting Editor on Space*



By far the largest manned spacecraft we have ever built is scheduled to circle 270 miles above the earth in 1972. Three-man crews, boosted up to it in Apollo Command and Service Modules, will serve successive four-to eight-week stints aboard it. Named Skylab, it will be our first space station—a forerunner of future orbital bases for the study of the earth beneath and the heavens beyond.

With Skylab, our manned space-flight program will take a new turn. While we are continuing our moon voyages, Skylab will herald still-long-

er flights. It will enrich our knowledge of earth, sun, and much else, as well. More than a dwelling in space, it offers a laboratory for all kinds of experiments in orbit.

Exploring man's limit in zero-g. Will tomorrow's long-voyaging spaceships need artificial gravity, or not? How long can men go weightless without ill effects? Skylab will probe for the answers far beyond any test yet. Gemini 7's crew spent 14 days in zero gravity; Russia's Soyuz 9 has just raised the mark to nearly 18 days. Skylab crews will go on to a 28-day

Continued

Dr. von Braun (left) plans coming articles with PS' Ernest V. Heyn (right), Associate Publisher and Editor-in-Chief, and J. Michael Hadley, Executive Vice-President and Publisher.



"No-hands" propulsion device for spacewalker will get a flight test in Orbital Workshop, in one of 47 Skylab experiments. Foot pedals control jets, beside feet, leaving rider's hands free for assembly of future space structures.



Overhead handrails (left) enable a weightless crewman to walk on Skylab's gridwork floors. Harness (right) keeps him from "drifting off" while asleep. In zero-g, it's comfortable to sleep upright.



Zero-gravity hand washer for Skylab crew is demonstrated by engineer pressing its water-jet button. Fixture, with openings to insert hands, confines water droplets and keeps them from becoming floating nuisances in cabin.

mission—and two more missions of up to 56 days each, if all goes well.

Striking innovations will suit the 83-foot-long, 68-ton Skylab for such extended visits.

As big as a three-bedroom house, it will provide more than 12,000 cubic feet of habitable space—nearly 40 times as much as does our next-roomiest Apollo Command Module.

It will literally have a more home-like atmosphere than any other U.S. spacecraft to date, in its main living-and-working section. Mercury, Gemini, and Apollo astronauts all have breathed pure oxygen—but medical men see risk of harm in doing it for a month or more. So Skylab will be our first spacecraft with a "two-gas" cabin atmosphere—like the air you breathe, a mixture of oxygen and nitrogen gases. However, its total pressure (five pounds to the square inch, "absolute") will be only one-third of atmospheric pressure on earth. So, to meet body needs, it will be much richer than air in oxygen: three-fourths oxygen, one-fourth nitrogen, by weight.

Skylab's design. Launched unmanned, Skylab is a cluster of five major elements: the Orbital Workshop, Multiple-Docking Adapter, Airlock Module, Apollo Telescope Mount, and Saturn V Instrument Unit.

The Orbital Workshop, actually a modified third stage of a Saturn V rocket, is the largest element—48 feet long. Its 21½-foot-diameter interior is divided by an aluminum-grid parti-

tion into two stories—the crew's living and sleeping quarters and a larger laboratory. The grid forms the floor of the lab and the ceiling of the crew's quarters, and has a central opening for passage between them. A similar grid forms the crew's-quarters floor.

By pushing lightly upward against overhead handrails, a crewman will be able to keep his footing on a floor and walk about it—an alternate way of locomotion in zero gravity to trying to float from place to place. Compartment doorways and furniture are oriented up and down to suit this procedure.

A window in the Orbital Workshop's wall enables astronauts inside to observe and photograph the earth. Small airlocks in the wall permit exposing instruments to space.

The Multiple-Docking Adapter—at the opposite end of the cluster—is the "spaceport" of Skylab, where a crew-ferrying Apollo Command and Service Module (CSM) docks to an axial port. Only one CSM will normally be docked to Skylab during occupancy. However, the Multiple-Docking Adapter has an extra port on its side where a second CSM could dock. This capability opens the first possibility, should trouble befall astronauts in space, of a "space-rescue" mission from earth.

The Airlock Module, bolted to the upper bulkhead of the Orbital Workshop, forms a passageway to it from the Multiple-Docking Adapter.

An EVA (extra-vehicular activity)

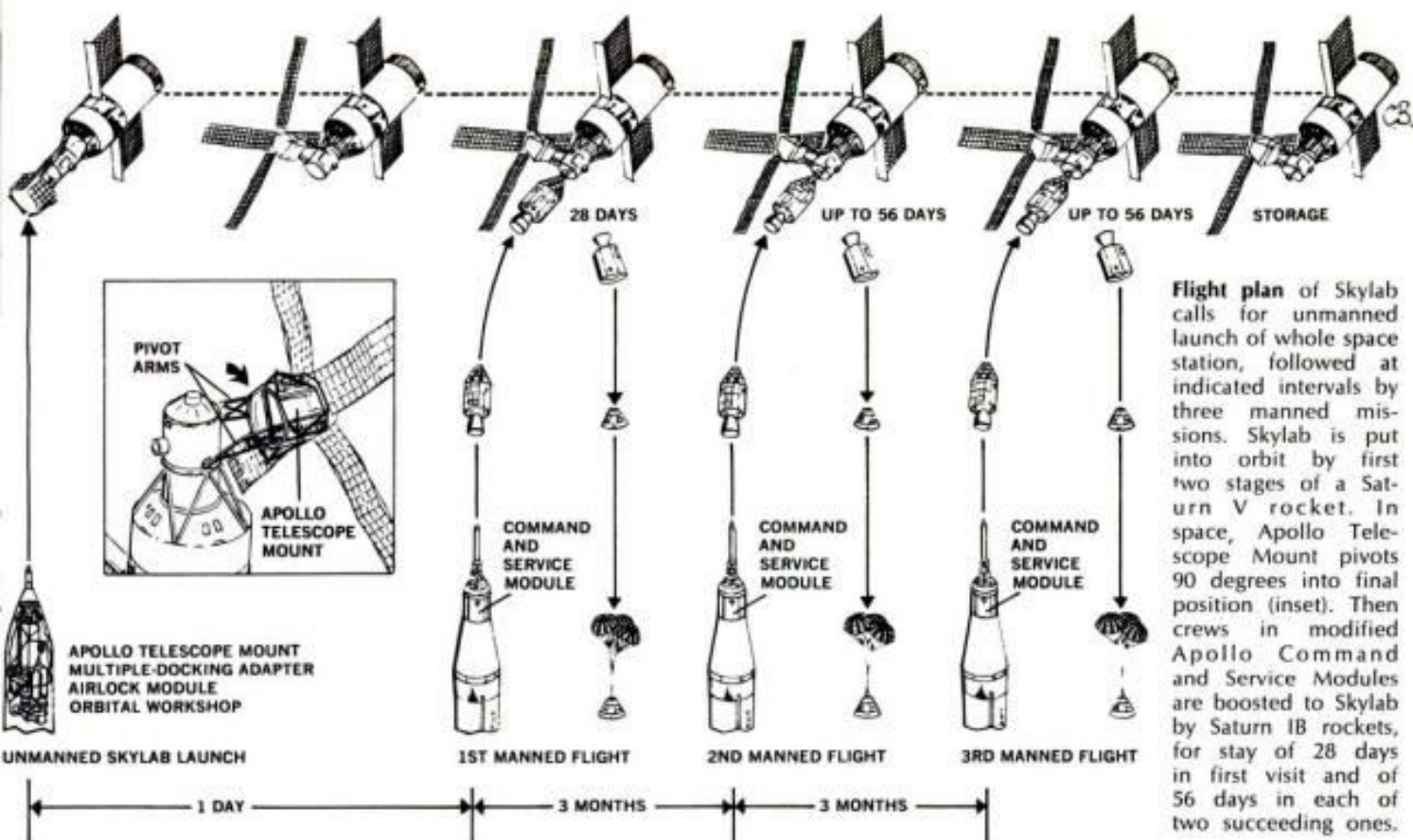
hatch in the Airlock Module enables a Skylab crewman to do "space-walking" jobs outside. The very purpose of the airlock is to permit opening this hatch without necessitating depressurization of the Orbital Workshop or the Multiple-Docking Adapter.

In addition, the Airlock Module contains the gear for electric-power control and distribution to all five elements of the cluster, as well as the life-support system and an assortment of additional equipment.

The Apollo Telescope Mount (ATM) is a full-fledged manned solar observatory. It will be operated from control panels in the pressurized Multiple-Docking Adapter. However, loading and retrieving its instruments' films (which will be brought back to earth) will require trips to the ATM by space-walking crewmen.

The Instrument Unit that serves Saturn V for navigation, guidance, and control is the final major element of Skylab. Ring-shaped, it encircles the Airlock Module. It is used only during the launch phase and the first 7½ hours of orbiting.

Immediately upon arrival in orbit, the gyroscopic platform in the Instrument Unit causes the entire cluster to rotate until it is broadside to the sun. In this position, the Orbital Workshop deploys its two 600-square-foot solar panels, attached to it like gigantic elephant ears. They supply the station with about 12 kilowatts of electric power.



Flight plan of Skylab calls for unmanned launch of whole space station, followed at indicated intervals by three manned missions. Skylab is put into orbit by first two stages of a Saturn V rocket. In space, Apollo Telescope Mount pivots 90 degrees into final position (inset). Then crews in modified Apollo Command and Service Modules are boosted to Skylab by Saturn IB rockets, for stay of 28 days in first visit and of 56 days in each of two succeeding ones.

The Instrument Unit also provides sequencing signals to rotate the ATM 90 degrees from stowed to operating position, and to deploy the ATM's windmill-like solar panels. They give the ATM its own power supply of 10½ kilowatts.

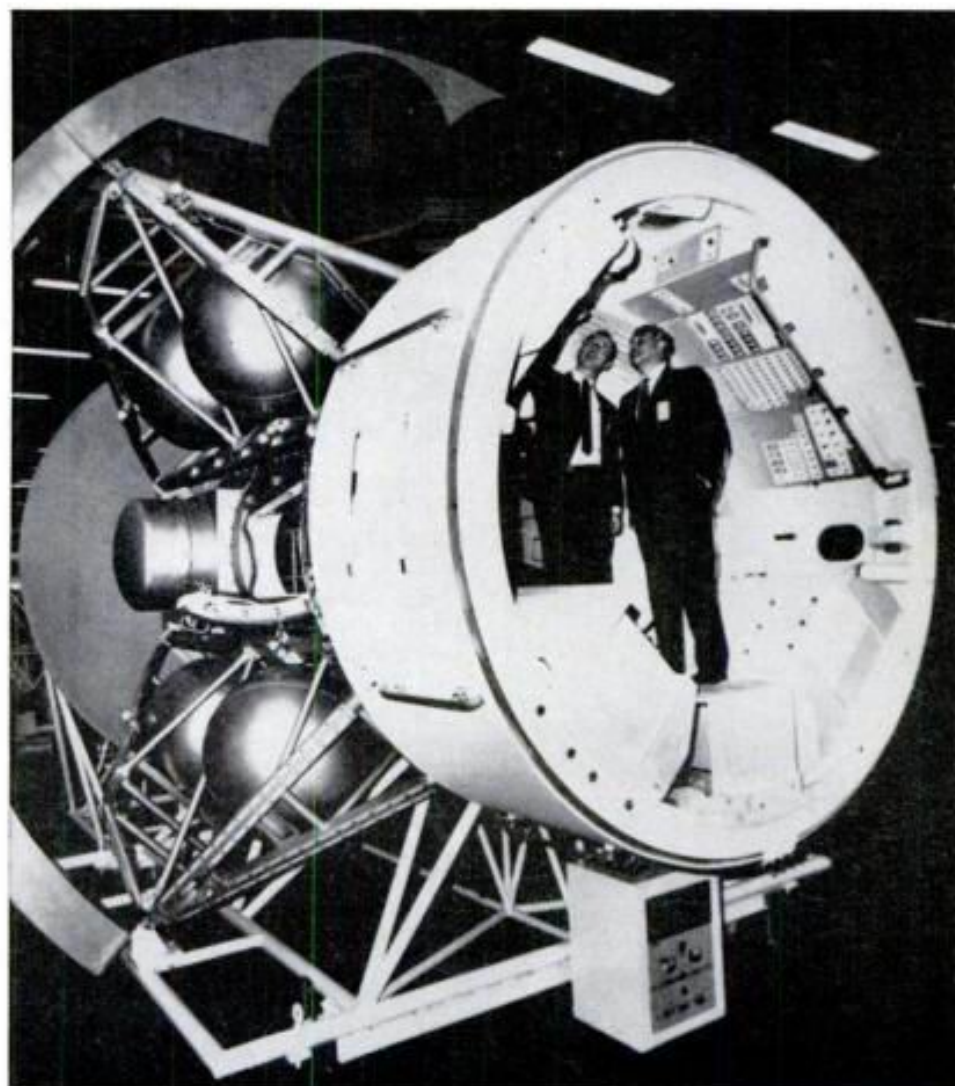
Once the ATM is in operation, a novel flywheel attitude-control system in it keeps the entire cluster in its sun-oriented attitude. This is necessary not only for solar observations and the solar-cell power supply, but also for the station's overall thermal balance.

In preparation for its three-man parties of guests, Skylab will be stocked with a 140-day supply of food, and enough breathing gases and water for still longer. For sleeping accommodations the Orbital Workshop provides a compartment where a crewman will zip himself up, sleeping-bag-style, in a wall-anchored harness—so as not to float about while he slumbers. Food-preparation and waste-disposal facilities complete Skylab's ample equipment for extended housekeeping in orbit.

What they'll do in Skylab. The Skylab program's specific objective is to conduct 47 different experiments in space medicine, crew operations, technology, earth resources, physics, and astronomy. Just a few examples must suffice here to illustrate their variety and ingenuity.

Effects of weightlessness on Skylab crewmen will be constantly monitored

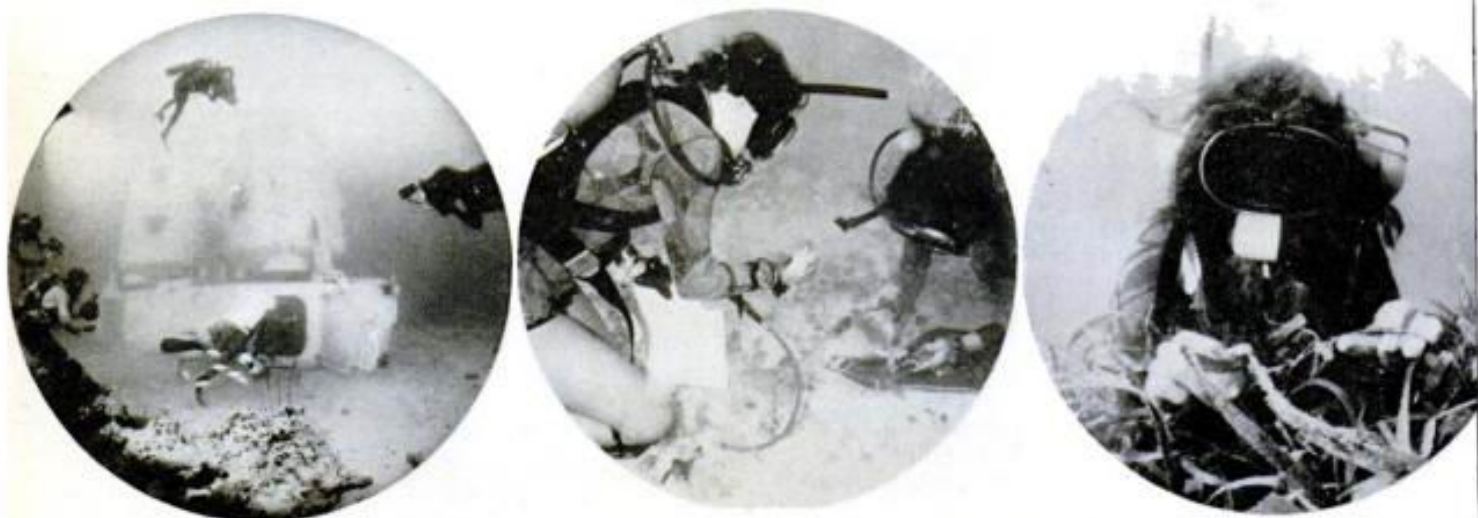
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Full-scale mockup of Skylab airlock, through "ferry" craft into the Orbital Workshop, is inspected by Dr. von Braun (right).

Our Consulting Editor for Oceans visits the 50-foot-deep habitat of the men and women at work on a new sea-floor experiment

Come Dive With Me to



Undersea glimpses show women aquanauts of Tektite II successfully carrying out a mission to study sea-bottom flora and fauna. The

By **CMDR. SCOTT CARPENTER, USN (RET.)**

World-renowned astronaut and aquanaut

When the seven-month, 17-mission Tektite II program in the U.S. Virgin Islands is completed at this month's end, it will mark a new step forward in undersea adventuring.

Ten crews of five divers each will have spent up to 20 days at a 50-foot depth. Seven other crews of two men each will have lived 100 feet down for

two weeks, if all has gone according to plan. Stays overlapping successive missions will have kept some divers under water for a month.

Last year at the same site—chosen for its warm and clear water—Tektite I's four aquanauts spent a record two months in a 50-foot-deep habitat ["Tektite Revisited," PS, Nov., '69].

This time, as many as 62 aquanauts are continuing and expanding the marine-science studies they began. Innovations in diving gear and techniques are being tested. Among Tektite II's many "firsts" has been the subsea debut of the first team of women aquanauts—"aquanettes" to some, "aquachicks" in Virgin Islanders' vernacular.

A first-hand view. To see what Tektite II was like, I traveled to the site, paid a 50-foot-deep visit to its main underwater habitat, and had an opportunity to watch its team of women aquanauts in action.

I timed my trip, near the end of June, to coincide with a crew change so I would be able to visit the GE-built habitat without interfering with the divers or their scientific programs. (Habitat visitors are not allowed, anyway, after the first day of occupation by a crew.) Permission for my trip was obtained from three of Tektite II's main sponsors—the Department of the Interior, General Electric, and NASA.

Tektite II's site is off St. John Island—a 30-minute boat ride from St. Thomas Island, usually under a blue sky and warm sun. The boat ties up near the Tektite II base camp, which normally houses 60 people. A short Jeep ride brings morning visitors to the chow hall in time for breakfast.

Some distance away on Beehive Cove is the Habitat Support Center. The main habitat, 800 feet directly offshore, is monitored and supplied with key services by this land base.



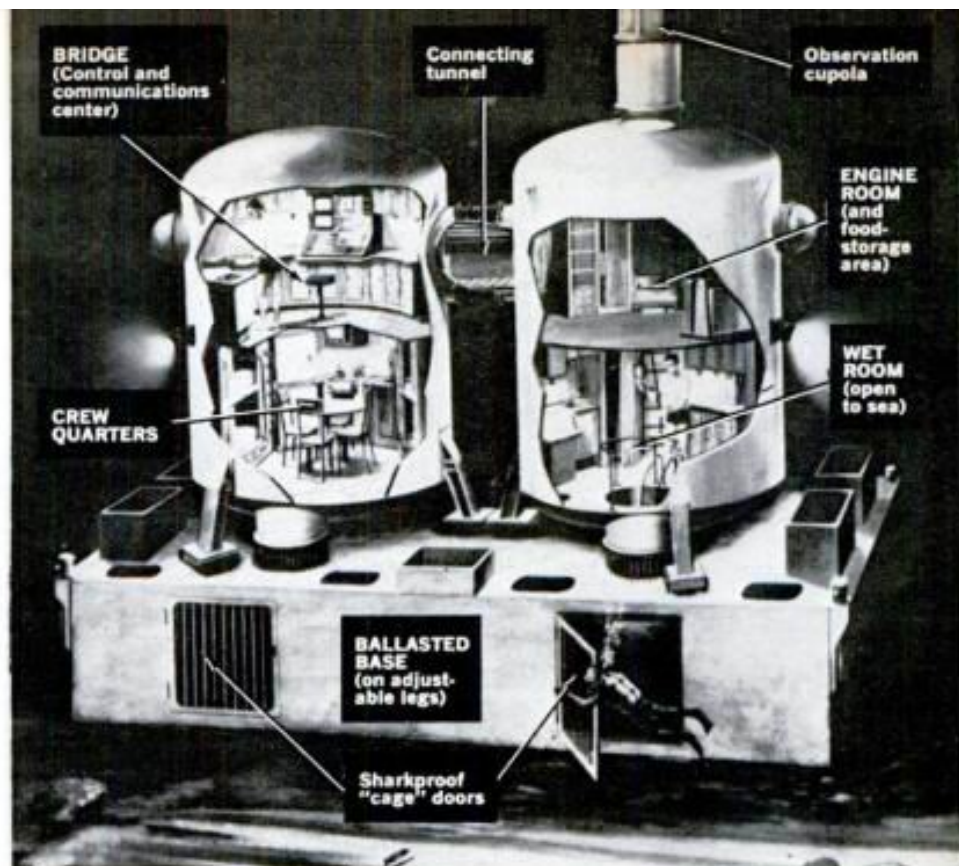
On a visit to submerged habitat, Cmdr. Carpenter (left) is shown its control and

communications center by John Van Derwalker, director of scientific programs.

Tektite II



hearsals for it gave author a vivid preview.



Tektite II habitat, 50 feet deep, accommodates crew of five for a stay of 14-20 days.

At a console in its control van, a watch officer and observers are in constant telephone communication with the habitat. TV screens show them what is happening in each of the habitat's compartments—and what is seen when aquanauts carry a camera outside. These displays can be video taped. Observers ashore can also listen in through open microphones in each habitat compartment.

At the shoreline are a diver-support pier and a support barge with decompression facilities on its deck. Also barge-mounted is equipment to supply the habitat from ashore with electricity, fresh water, and other needs, through an umbilical cluster of cables and hoses running along the sea floor.

A visit to the habitat. To get to the habitat, you swim out to it from shore, with scuba-diving equipment. For my visit I donned standard open-circuit scuba gear and swim fins. My guide was John Van Derwalker, the project's scientific-programs director, who has probably spent more time working in and out of the habitat than any other Tektite diver.

Starting from the support barge, we swam along the bottom toward the habitat. Its white bulk became visible a little less than 100 feet away. We reached it about five minutes after leaving the shore.

To enter the habitat, we swam into the open four-foot-diameter hatchway in the floor of its "wet" compartment for divers' use. Since the water pressure at the habitat's depth is exactly balanced by the 39.9-pound-per-

square-inch pressure of its own atmosphere (or just a little more than double the pressure of the air you breathe), no water rises above the open hatch's level.

The five-man habitat consists of two 12-foot-diameter cylinders, each 18 feet high and divided into two compartments. Divers make their excursions from the wet room we first entered, which contains diving gear, a small lab, and a hot shower.

The compartment above, rather fancifully called the "engine room," actually holds transformers, switchgear, food stored in a large freezer, and the environmental-control system that maintains the habitat's pressurized atmosphere of 93 percent nitrogen, seven percent oxygen.

Through a 4½-foot-diameter tunnel, we passed from this compartment to the "bridge," the control and communications center in the upper part of the other cylinder. The bridge provides a bunk for one member of the crew of five, its "engineer." The rest of the crew sleep in the compartment below, the crew quarters, which also serves as a living, dining, and recreation room. Windows in the sides of the habitat, and in an observation cupola projecting above it, give the occupants a view of marine life outside.

During our tour we saw several divers preparing the habitat for its next mission, and a photographer who snapped pictures of us.

When we swam back to shore after an hour's inspection of the habitat,



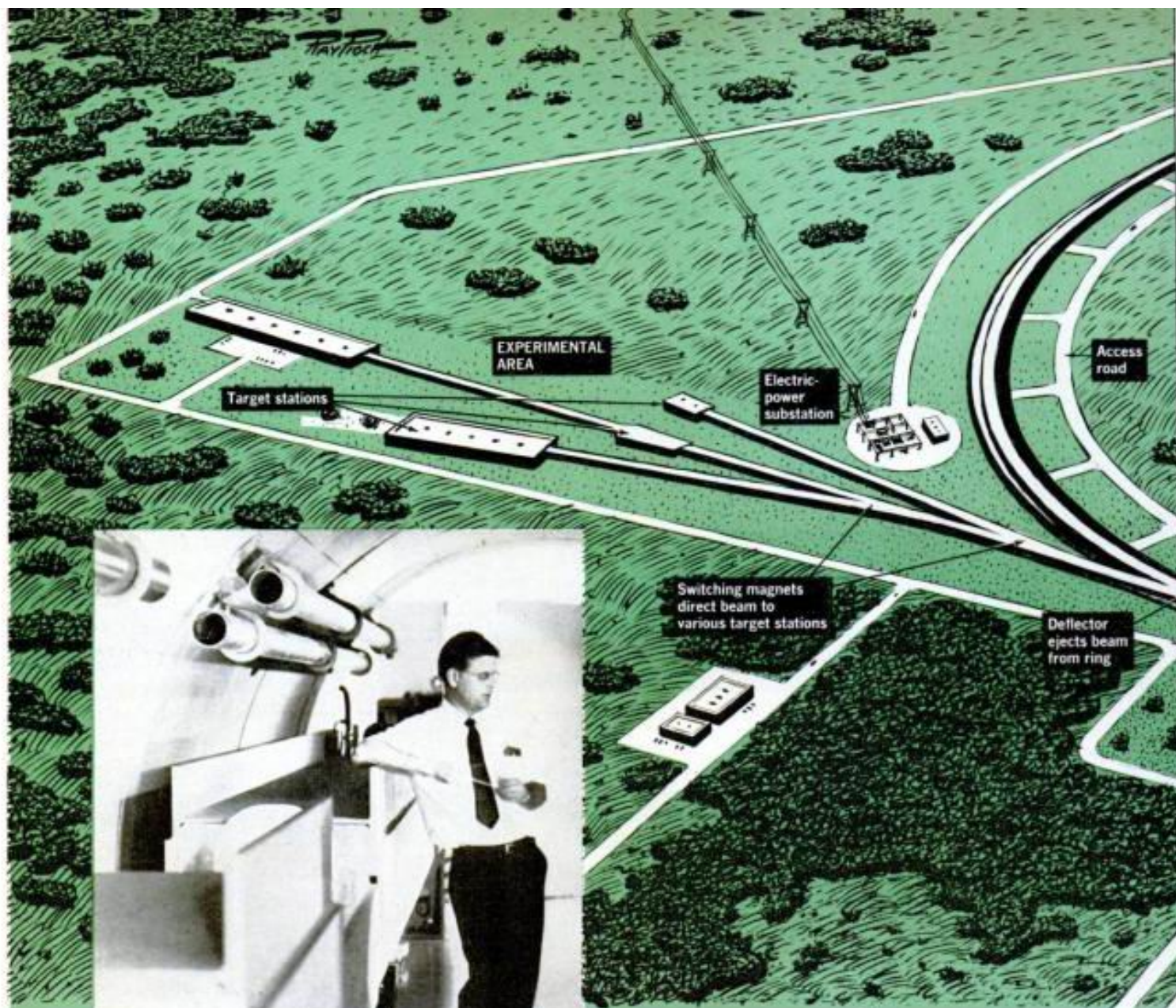
"Minitat," the 100-foot-deep outpost of Tektite II for deeper experiments, is designed for a two-week stay by crew of two.

our dive to its depth had been too brief to require going through decompression for readjustment to normal atmospheric pressure. But it's a different story for the crew of an extended Tektite II mission.

The personnel transfer capsule. After 24 to 36 hours of submergence at the habitat's depth, the crew members are "saturated"—their blood and tissues have dissolved the maximum possible amount of the pressurized gas they breathe. Returning them suddenly to sea-level pressure would release dissolved nitrogen gas in bubbles, and bring on the painful and dangerous "bends."

So, when a crew leaves the habitat at a mission's end, they swim to a point on the bottom beside the support barge, where the water is 40 feet deep. Still under pressure, they are lifted to the surface by successive trips of a "personnel transfer capsule," a spherical two-man diving

[\[Continued on page 142\]](#)



Boosting original design's power while slashing its cost was near-miracle achieved by Prof. R. R. Wilson, pictured in mock-up of section of ring.



How new atom smasher compares in size with biggest existing ones in world and U.S. is shown to scale above. Current record-holder is 76-BEV proton synchrotron of Institute for High Energy Physics at Serpukhov, in Russia. Next comes 33-BEV one at Brookhaven National Lab, Upton, N.Y.

YOUR PREVIEW OF THE World's

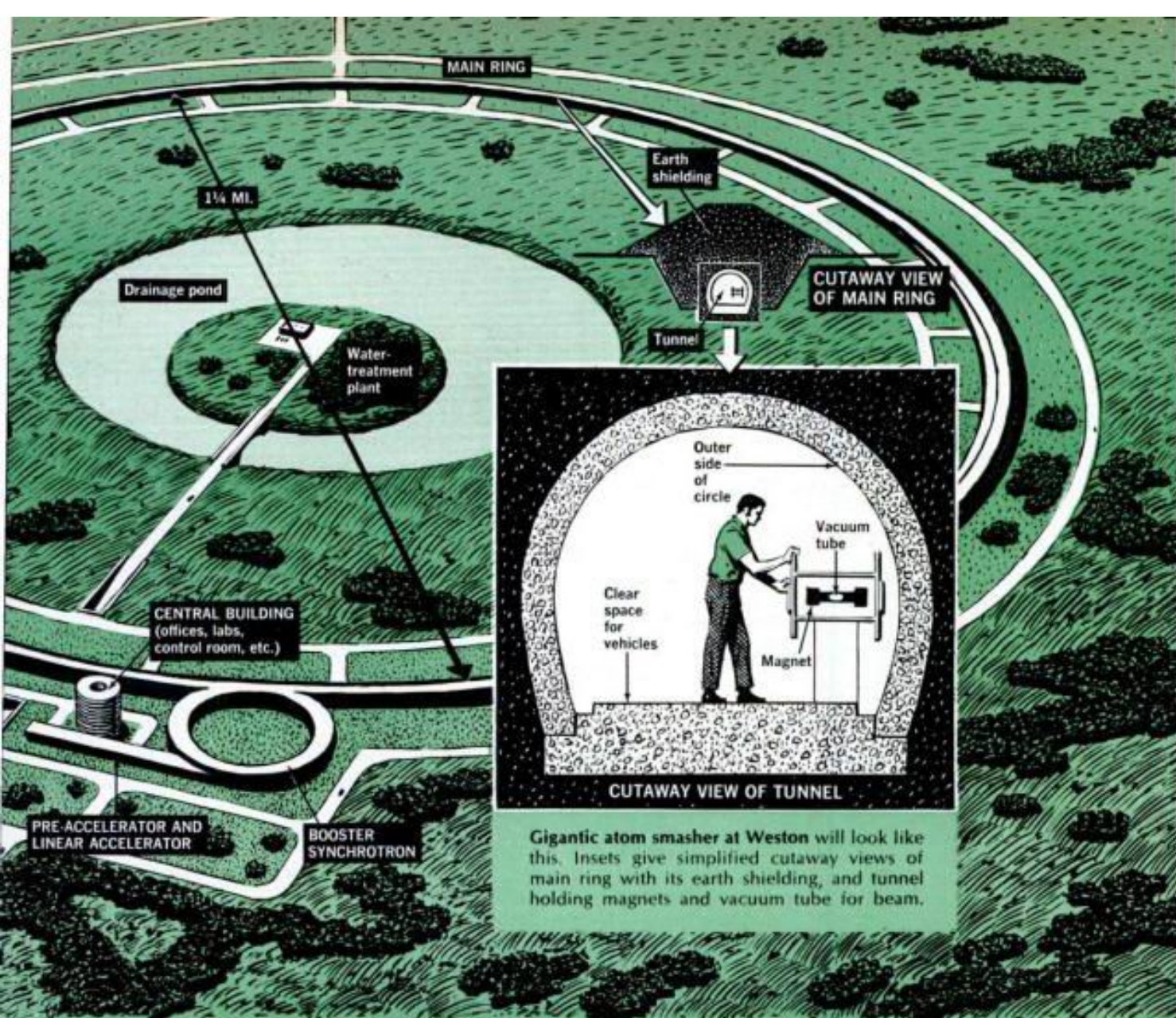
A spectacular 1¼-mile-diameter ring machine wielding 200 to 500 billion electron volts may bare the innermost secrets of matter

By ALDEN P. ARMAGNAC
DRAWINGS BY RAY PIOCH

This will be the colossus of them all—the mightiest atom smasher the world has ever seen.

Some 30 miles west of Chicago, the spectacular \$250-million ring-shaped machine is well along toward completion for the new National Accelerator Laboratory at Weston, Ill. By recent announcement it may go into action as soon as mid-1971, a year ahead of schedule.

A mile and a quarter in diameter, it will be the biggest instrument on earth for basic research.



Gigantic atom smasher at Weston will look like this. Insets give simplified cutaway views of main ring with its earth shielding, and tunnel holding magnets and vacuum tube for beam.

Mightiest ATOM SMASHER

Largest appliance ever to be plugged into a commercial power line, it will run up an electric bill of something like \$2 million a year.

Called a proton synchrotron, it will boost speeding protons—the cores of hydrogen atoms—to fantastic energies of 200 to 500 billion electron volts (BEV). That will bring back to America the record held since 1967 by a 76-BEV atom smasher at Serpukhov in Russia, the world's most powerful today.

Hurled out of the huge ring on a tangent, the Weston machine's atomic bullets will crash into targets at a speed of at least 99.999 percent of the velocity of light, to blast out the innermost secrets of matter.

Giant ring runs underground. At the 6,800-acre flat-land site of the Weston accelerator, earlier this year, a visitor could see its gigantic main ring taking shape in a great ditch 20 feet deep, flanked by clanking cranes. Being lowered into the excavation were 10-foot sections of precast concrete that, aligned and joined end to end,

would form a circular tunnel. Horseshoe-shaped in cross-section, the tunnel will be eight feet high and 10 feet wide. For shielding against dangerous radiation from the ring, a mound of earth 22 to 33 feet thick will cover it.

Already completed and successfully tested above ground last March, a prototype section of the endless four-mile-long tunnel gives a viewer an advance look at what is to go inside it.

Along an interior wall, on the side away from the ring's center, will run a continuous string of girder-shaped electromagnets—nearly 1,000 in all. They include "bending" magnets to make the stream of hurtling protons follow a circular path, and "focusing" magnets to compress the sausage-shaped clusters of speeding particles into a beam small enough to pass through the "barrel" of the atom gun without touching it.

Running between the magnets' poles, this "gun barrel" is a stainless-steel vacuum tube of surprisingly dimin-

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were bogged down in bloody cave fighting during the hunt for bin Laden, Lafontant had lunch with fellow space expert Franz Gayl in the Pentagon cafeteria. Gayl, also a former Marine with significant influence in the private sector, brainstorms new technologies for the Corps's Plans, Policies, and Operations Department. Lafontant suggested that a space transport could have allowed Marines to nab bin Laden without a major assault—and before the terrorist leader could disappear into Afghanistan's caves. Gayl was skeptical of its feasibility—the idea of military space transport has been around for decades yet has never been deemed viable enough to enter active development—but he was impressed by the elegance of the solution and its use of military technology that he knew to be in the works.

Together, Lafontant and Gayl formally presented their concept to Gayl's boss at the Pentagon, brigadier general Richard Zilmer, and then to lieutenant

general Emil Bedard, the office's deputy commandant, who endorsed it on July 22, 2002, adding space transport to the Marines' official wish list. But the technology—reusable and advanced propulsion, sophisticated heat shielding—wasn't ready. Just a year earlier, two joint NASA and Air Force programs to develop similar reusable launch vehicles, or RLVs, had been canceled because of problems with their single-stage engines. The idea was far ahead of the technological curve.

But Lafontant was patient. He continued to refine and promote the space-transport idea until it was a fixture in the collective imagination of the Marines' space community. Soon Sustain found a home at the Corps's Space Integration Branch in Virginia, where Wassink directs a 100-person team of satellite technicians who connect Marine commanders to operations around the world. Wassink was interested in the Sustain project, but the Marine Corps is a small force under

the umbrella of the Navy and receives just 4 percent of military funding. Sustain is "certainly not something the Marine Corps would be able to acquire on its own," he admits.

Zilmer agreed and introduced the Sustain concept to Congress. In an address to a Senate committee in July 2003, he outlined the Marine strategy. "We must coordinate and synthesize our technology needs with other Department of Defense and nonmilitary users," Zilmer told the committee. He mentioned NASA as a possible partner. Lafontant also foresaw the Air Force developing the carrier aircraft and the Defense Advanced Research Projects Agency (Darpa), the Pentagon's experimental-science arm, overseeing the design of the lander. Zilmer's testimony was part of a broad campaign that Lafontant and the other Sustain advocates launched to sell the idea to Congress, NASA, the Air Force and Darpa, and to the industry partners that would build the

THE EXPRESS ROUTE

A future long-range lander will launch into suborbital space from a carrier craft [1]. The lander will fire its own rockets for the ascent into space and then coast to the conflict area [2], where it will reenter the atmosphere and fly to a touchdown [3].



As any battlefield commander will tell you, getting troops to the fight can be as difficult as winning it. And for modern-day soldiers, the sites of conflict are so far-flung, and the political considerations of even flying over another country so complicated, that rapid entry has become nearly impossible. If a group of Marine Corps visionaries have their way, however, 30 years from now, Marines could touch down anywhere on the globe in less than two hours, without needing to negotiate passage through foreign airspace. The breathtaking efficiency of such a delivery system could change forever the way the U.S. does battle.

The proposal, part of the Corps's push toward greater speed and flexibility, is called Small Unit Space Transport and Insertion, or Sustain. Using a suborbital transport—that is, a vehicle that flies into space to achieve high travel speeds but doesn't actually enter orbit—the Corps will be able, in effect, to instantaneously deliver Marine squads anywhere on Earth. The effort is led by Roosevelt Lafontant, a former Marine lieutenant colonel now employed by the Schafer Corporation, a military-technology consulting firm working with the Marines. Insertion from space, Lafontant explains, makes it possible for the Marines—typically the first military branch called on for emergency missions—to avoid all the usual complications that can delay or end key missions. No waiting for permission from an allied nation, no dangerous rendezvous in the desert, no slow helicopter flights over mountainous terrain. Instead, Marines could someday have an unmatched element of surprise, allowing them to do everything from reinforce Special Forces to rescue hostages thousands of miles away.

"Sustain is simply an ability to move Marines very rapidly from one place to another," says Marine colonel Jack Wassink, director of the Corps's Space Integration Branch in Arlington, Virginia, where the program is based. "Space lends itself to that role."

The program is quickly gaining traction. Congress has expressed interest, because of the obvious usefulness of the capability it promises. And the technologies necessary to make it happen, from hypersonic propulsion

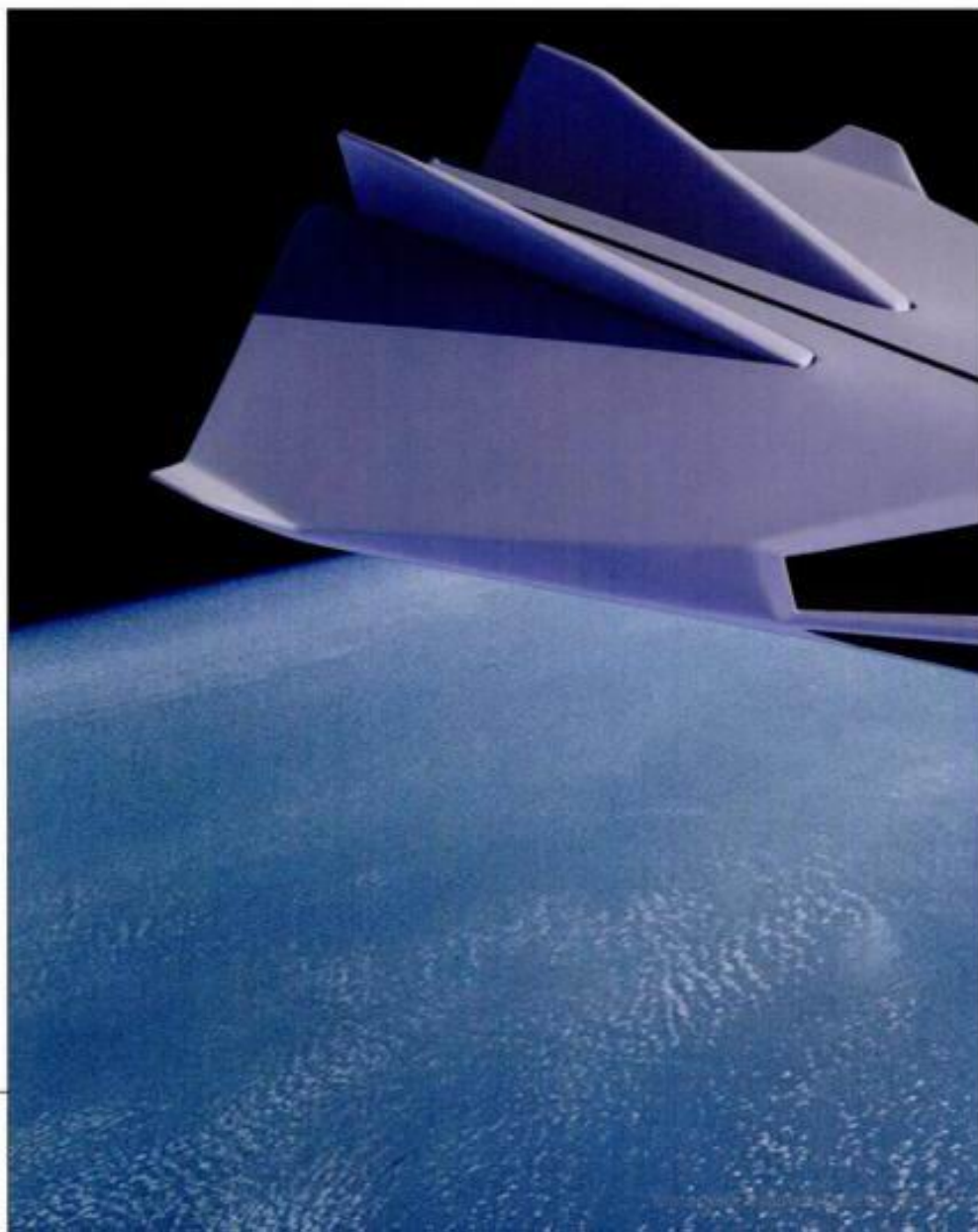
systems to new composite materials needed to make the vehicle lightweight yet strong, are in advanced development in military labs across the country. The Marines expect to fly a prototype in 15 years, most likely a two-stage system using a carrier aircraft that will

launch a lander into orbit from high altitude. Production models could show up around 2030, a date that isn't quite as far away as it seems. Consider that the F-22 Raptor fighter is now entering service after 22 years of development.

But the whole idea still rings of science fiction, and the question is whether its proponents can corral the various technologies together to make the project possible. "Sustain is not a pipe dream," Lafontant says. "It just needs to gel."

OVERSTEPPING BOUNDARIES

Finding routes through diplomatically friendly airspace and then arranging for timely delivery of U.S. forces are key complications, especially on today's world political stage. Sustain would solve both problems in a single stroke.



According to international agreement, a nation's airspace extends 50 miles from the Earth's surface, just short of low orbit. A spacecraft would allow the U.S. to step over other countries and insert forces where they're needed.

Each Sustain lander is intended to hold a squad of 13 Marines. Mounted on wedge-shaped carrier aircraft, the lander would detach, climb, and accelerate with scramjet engines to 100,000 feet and then fire rocket engines to get above 50 miles, following an arc over hostile countries. Composite shields would absorb or deflect the searing heat of reentry as the vehicles angle for the landing zone.

Lafontant arrived at this Space Marines vision after years of analyzing military space needs. A 44-year-old Queens, New York, native who joined the Corps in 1984 as an infantry offi-

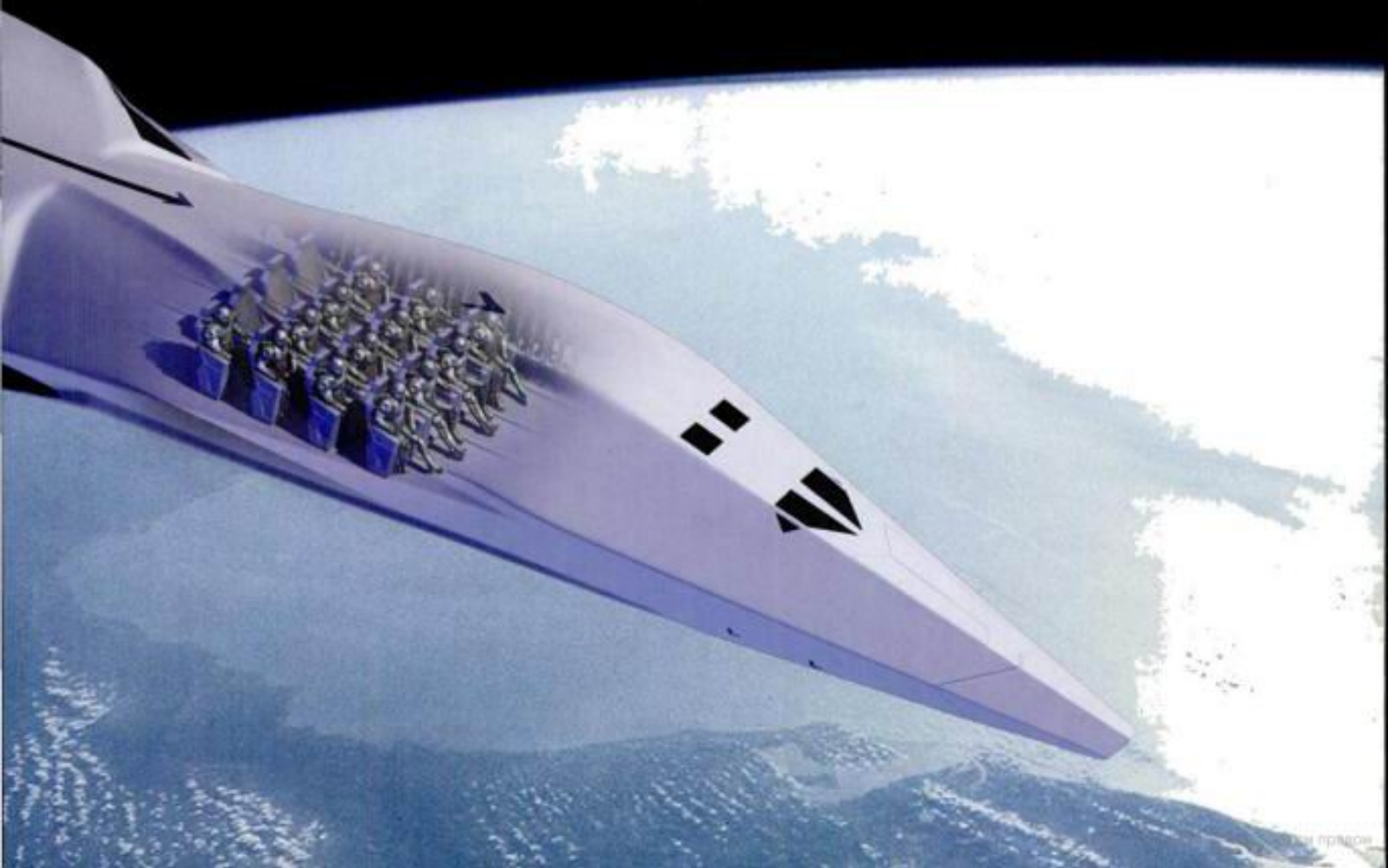
cer and progressed through Naval Postgraduate School in Monterey, California, where he studied space systems operations and joined the small fraternity of Marine Space Operations Officers. In 2001 he took a job in the Pentagon working for the National Reconnaissance Office. He was serving as liaison to the Joint Chiefs of Staff in November 2001 when the Marine Corps launched its deepest air assault ever.

Five hundred Marines from the 15th Marine Expeditionary Unit prepared to fly 441 miles through the mountains of northern Pakistan in CH-53E Sea Stallion helicopters to capture an airstrip near Kandahar, Afghanistan. It was to be the beginning of the first large offensive against the Taliban and Al Qaeda. If all went well, the Marines expected to walk away with Osama bin Laden.

But political considerations sabotaged the mission. For weeks, the Marines had bobbed on the Indian Ocean aboard two assault ships while State Department officials negotiated with Pakistan for the right to fly through the country's airspace. Pakistan granted access only after winning economic and military concessions that, some say, have reinforced a repressive regime. When U.S. troops finally touched down on November 25, bin Laden's trail was cold. "We ended up selling our soul to the devil to get through," Lafontant says. He grew determined to find a way around that sort of diplomatic entanglement. "What if we don't have to have anybody's permission?" he asked himself. "What if we just go above and drop in?"

In April of that year, while Marines

MOD SQUAD The lander, with the squad of 13 Marines and two pilots on board, will travel the 7,000 miles to Southeast Asia in mere minutes by flying above the atmosphere.





DENNIS GRAY

Sitting dead in the water, *Yamato 1* looks like a rocket. It doesn't take off like one, though. During its first sea trial in June, the streamlined ship didn't even move fast enough to throw a wake.

Yet that maiden voyage could become as important in marine history as the 1807 launching of Robert Fulton's steam-powered *Clermont* or the *Nautilus* submarine's first trip under nuclear power in 1955. *Yamato*'s propellerless technology may eventually move ships faster and with less noise than any propulsion system yet developed. But with *Yamato* achieving a speed of only slightly more than six knots (about seven mph) as it glided through the harbor in Kobe, Japan,

SUPERCON GOES TO SEA

**With no propellers to slow them down,
ships and submarines powered by
superconducting electromagnets may
one day cross oceans in record time.**

BY DENNIS NORMILE



Yamato 1, the world's first full-scale ship to use superconducting electromagnets for propulsion, made its maiden voyage in Japan's Kobe harbor in June. Crew members monitor the ship's performance from a cockpit loaded with electronic gear (top left).

DENNIS GRAY

the technology has a long way to go. Before magnet-driven ships can become competitive with conventional watercraft, researchers will need to develop superconducting magnets that are more powerful and lightweight than any known today.

In place of a propeller or paddle wheel, *Yamato* uses jets of water produced by a magnetohydrodynamic (MHD) propulsion system. MHD technology is based on a fundamental law of electromagnetism: When a magnetic field and an electric current intersect in a liquid, their repulsive interaction propels the liquid in a direction perpendicular to both the field and the current.

In *Yamato*, the liquid is seawater, which conducts electricity because of

the salt it contains. The boat's futuristic shape channels the seawater into two MHD thrusters on the bottom of the hull—one on each side.

Inside each thruster, the seawater flows into six identical tubes, arranged in a circle like a cluster of rocket engines. The ten-inch-diameter tubes are individually wrapped in saddle-shaped superconducting magnetic coils made of niobium-titanium alloy filaments packed into wires with copper cores and shells. Liquid helium cools the coils to -452.13°F , just a few degrees above absolute zero, keeping them in a superconducting state in which they have almost no resistance to electricity.

Electricity flowing through the coils generates powerful magnetic fields within the thruster tubes. When an electric current is passed between a

pair of electrodes inside each tube, seawater is forcefully ejected from the tubes, jetting the boat forward.

The MHD thrusters have several advantages over conventional propulsion systems. Most important, they will enable ships and submarines to travel at high speed. Visionaries anticipate speeds of up to 100 knots (about 115 mph), although researchers associated with the *Yamato* project regard that goal as extremely optimistic.

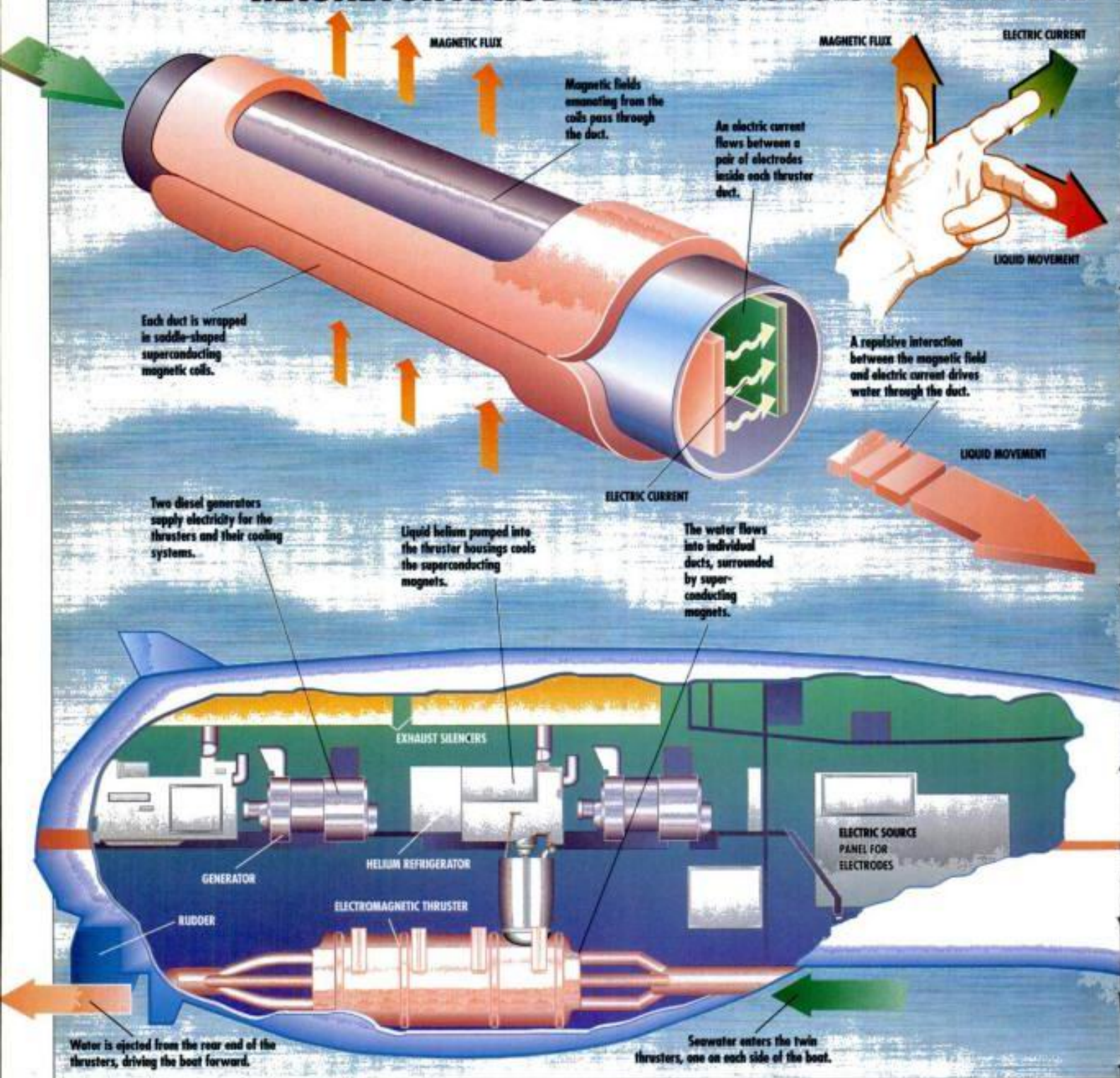
Kensaku Imaichi, professor emeritus at Osaka University in Japan and a key figure in the design of *Yamato 1*, believes the technology may have commercial ships cruising at 40 to 50 knots (46 to 58 mph) sometime in the next century. Speeds could go even higher if breakthroughs can be made in hull materials and ship stability.

DUCTIVITY



**Popular
Science**
NOVEMBER 1992

MAGNETOHYDRODYNAMIC PROPULSION AND THE



The speed of propeller-driven vessels is limited by a phenomenon known as cavitation. If the propeller turns too fast, an area of low pressure forms in front of the churning blades, causing the water to vaporize. This not only reduces a ship's efficiency, but can even destroy its propeller.

"By doing away with the propellers, we can avoid the phenomenon," says Seizo Motora, professor emeritus at the University of Tokyo and head of a scientific committee that designed Yamato's hull.

The second major advantage of MHD propulsion is silence. "There is no noise from a propeller, there is no noise from cavitation," Motora says.

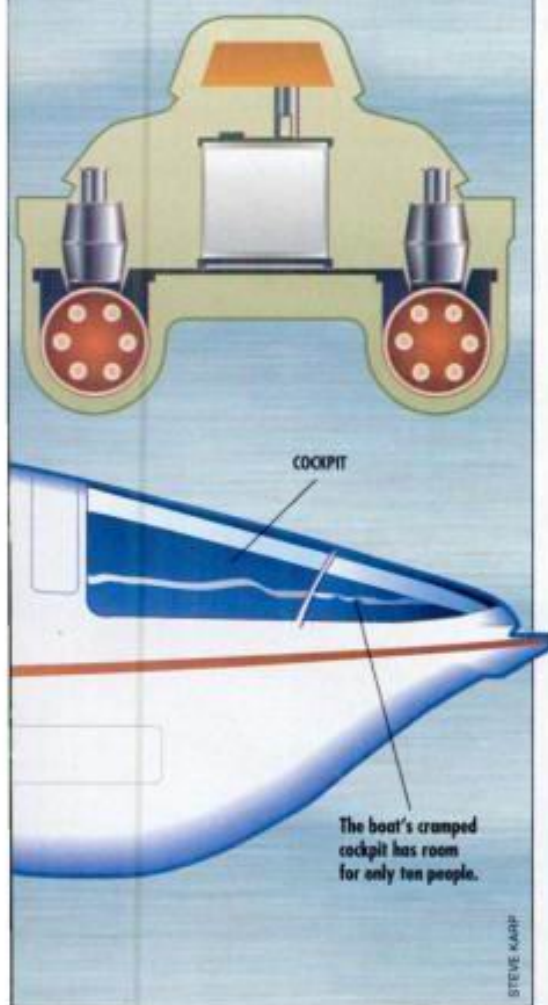
Silence is a central part of the plot of Tom Clancy's novel *The Hunt for Red October*, in which a Soviet submarine's noiseless propulsion system renders the vessel virtually undetectable by sonar. Clancy says that his fictional submarine propulsion system, dubbed the caterpillar drive, is not based on MHD technology. But the quest for stealthy submarines is what fuels in-

terest in MHD propulsion in most countries, including the United States (see American Stealth-Submarine Research on Hold).

Because MHD thrusters have no moving parts, they are not only quiet and vibration-free, but are also expected to have lower maintenance requirements than conventional propulsion systems. And with no need for a drive shaft to link the power source to the propulsion system, shipbuilders could experiment with new ship designs. Among the possibilities: cargo sub-

"LEFT-HAND RULE"

The "left-hand rule" is a simple method for calculating the interaction between a magnetic field and an electric current in a liquid. If you hold your left hand in the position shown in the drawing at left, you can use three of your fingers to represent the three forces at work. With your thumb pointed in the direction of magnetic flux, and your index finger pointed in the direction the electric current flows, your middle finger will indicate the direction in which the liquid will move as a result of the repulsive interaction between the magnetic field and electric current. You can test this rule on the drawing at far left, which shows one of Yamato's thruster ducts. Six of these ducts are arranged in a circle within each of Yamato's two thruster pods (below). Diesel generators and cooling systems fill most of the remaining space inside the boat (bottom).



Hoisting *Yamato 1* from the water exposes its unique hull design. This view shows the boat's thruster outlets.

marines shaped like jet airplanes and catamaran-style ocean liners.

A primary goal of the consortium that built *Yamato 1* was to revitalize the stagnant Japanese shipbuilding industry. The Ship and Ocean Foundation, a private organization that sponsored the \$40 million project, received research and manufacturing support from Japanese giants such as Toshiba, Kobe Steel, and Sumitomo Electric. Mitsubishi Heavy Industries supervised the construction of *Yamato 1* at its shipyard in Kobe.

The Japanese researchers aim to develop fast, fuel-efficient commercial ships that could eventually ferry California oranges to Japan in less than a week, a trip that currently takes about two weeks. The technology might even be used to construct large cargo submarines, which could dive below the ocean surface to avoid storms. MHD propulsion might also be used in submarine ferries that would transport passengers between Japan's numerous islands.

If the Ship and Ocean Foundation has its way, MHD technology will never be used for military gain. "We will restrict the use [of the technology] to peaceful purposes," vows Yohei Sasakawa, director of the foundation and chairman of the steering committee for the *Yamato* project.

Like many technologies now being developed in Japan, MHD propulsion was first proposed by American scientists. Several researchers published papers on the subject in the early 1960s. A few years after the first papers appeared, Stewart Way, a Westinghouse Research Center consultant who collaborated with an engi-

neer at the University of California at Santa Barbara, used an MHD thruster to propel a small model submarine. But Way used ordinary magnets rather than superconducting ones, and scientists concluded that the technology would have to await more efficient methods of generating strong magnetic fields.

In 1968, a report on Way's research reached Yoshiro Saji, who had recently joined the faculty of Kobe Mercantile Marine University. Saji had been looking for some way to apply his specialty—cryogenics—to ships.

Saji had worked with liquid helium and knew of its role in superconductivity. With a boiling point of 4.2°K (-452.13°F), liquid helium is used to cool superconducting alloys down to their critical temperature—the temperature at which electrical resistance disappears.

Saji realized that the strong magnetic field required to boost the efficiency of MHD propulsion could be generated by a superconducting coil. He spent five years on theoretical work and started actual experiments in 1973. In 1978, Saji and a group of colleagues succeeded in propelling a superconducting MHD model ship through a tank of seawater. There was only one problem: The miniature ship wouldn't go straight.

"No matter what we did, it always turned. I thought it was really strange," Saji says.

The model was 4.5 feet long, with the superconducting coil and electrodes in a fin sticking straight down from the bottom of the boat. The coil was a simple oval immersed in a liquid helium bath, and the electrodes were placed above and below the coil. In this arrangement, called an external-field system, the electromagnet does not surround a water-filled duct. Instead, the magnetic field is projected into the open water below the boat. That was the problem.

Earth's magnetism increased the strength of the magnetic field on one side of the fin and decreased it on the other, generating more propulsion on one side of the model. When Saji had the water tank reoriented along a line from magnetic north to south, the boat went straight.

To avoid the influence of Earth's magnetic field, the superconducting coil and the electrodes were



MATSHIRO WADA / GUMMA LIAISON

laid horizontally on the flat hull of Saji's next model. In 1983, this 1.1-ton, 11.5-foot-long model achieved a speed of 2.5 feet per second.

Saji's work attracted the attention of Sasakawa, scion of a wealthy philanthropic family with longstanding ties to Japan's shipbuilding industry. Sasakawa asked for Saji's cooperation in taking the work under the aegis of the family-dominated Japan Foundation for Shipbuilding Advancement, now known as the Ship and Ocean Foundation. The foundation recruited scientists from industry, government, and academia to take part in the design of *Yamato 1*—the ship's name comes from one of the earliest civilizations on the Japanese islands. *Yamato* was also the name of a massive World War II battleship sunk by Allied planes in 1945 as it headed toward Okinawa.

Scientific committees assigned to tackle various aspects of the ship's design began their work in 1985. The committee designing the thrusters

soon decided to adopt an internal-field system. The researchers were worried that the uncontrolled magnetic fields emanating from an external-field system might affect other boats and the marine environment.

The committee built a small internal-field thruster, loaded it in a model, and successfully sailed it through a tank of water. The thruster had a superconducting coil wrapped around a single water duct.

For the actual ship, however, the thruster committee decided to arrange six ducts in a circle. The committee members claimed this would virtually eliminate magnetic radiation leakage, because the stray flux emanating from one coil would be drawn into its neighbor. (The effects of magnetic fields on the human body are unknown ["Electromagnetic Fields: In Search of the Truth," Dec. '91].)

While models demonstrated the MHD technology, scaling it up proved troublesome. The first sea trial, two years behind schedule, was cut short

when "quench" warning signals lit up in the ship's cockpit. Quench is the phenomenon in which a superconducting coil slips out of the superconducting state.

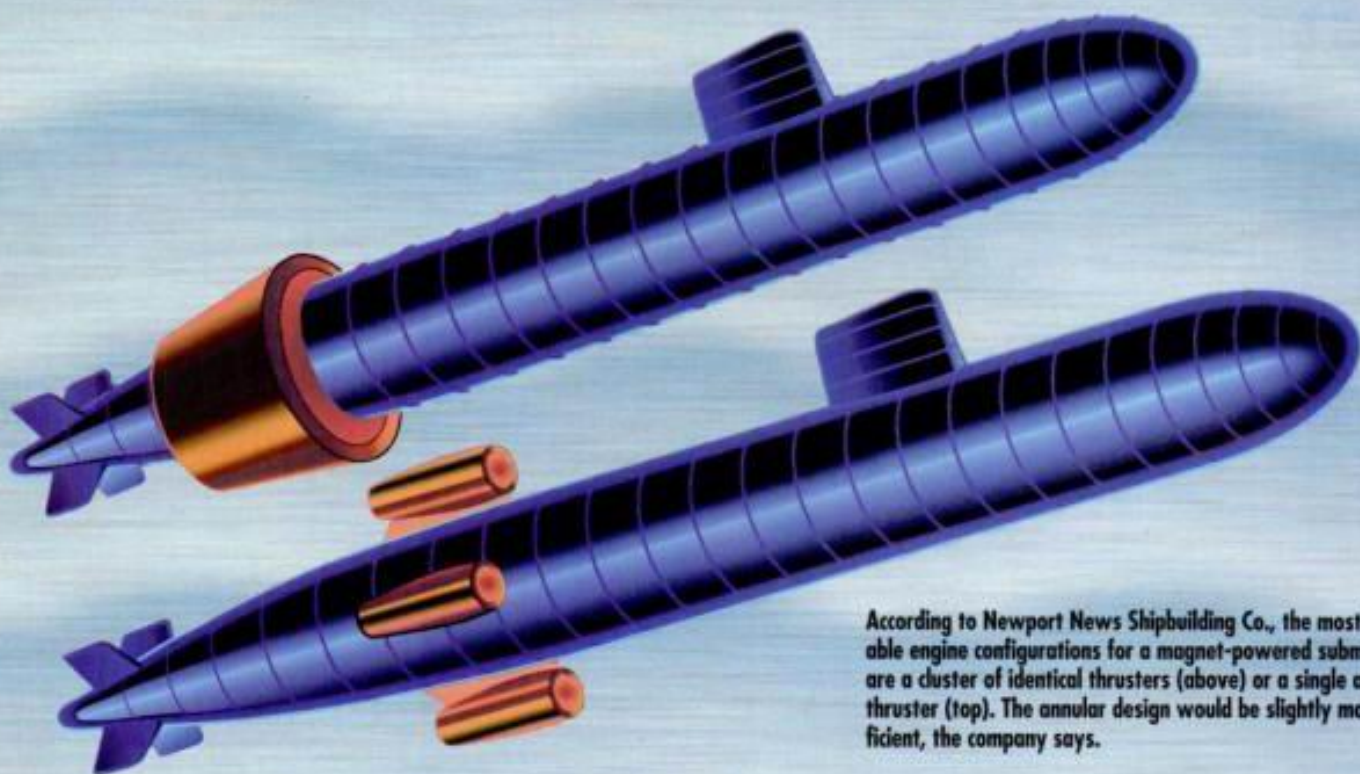
"Even if an unimaginably small portion of the coil slips into ordinary conducting mode, it generates an enormous amount of heat, which propagates throughout the system," explains Imaichi, who heads the thruster committee.

A sudden rise in temperature could destroy the coil, so *Yamato 1* is wired with sensors that constantly check for anomalies that might presage quench. "If the sensors are too sensitive, that interferes with ordinary operation," Imaichi says.

That seems to have been the case on the maiden voyage. Apparently, heat leaking through a gap around some electrical lead cables set off the warning signals.

The signal glitch was a minor detraction from the day's success. In just seven years, the Japanese team had

AMERICAN STEALTH-SUBMARINE RESEARCH ON HOLD



According to Newport News Shipbuilding Co., the most suitable engine configurations for a magnet-powered submarine are a cluster of identical thrusters (above) or a single annular thruster (top). The annular design would be slightly more efficient, the company says.

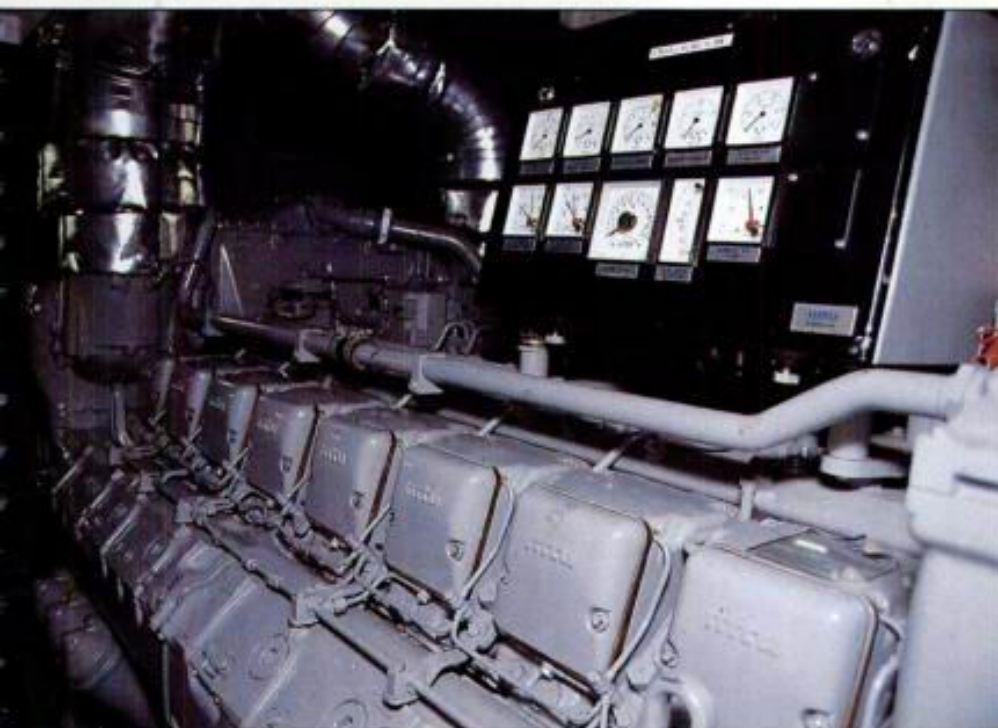
Although the United States pioneered the development of magnet-powered ships in the early 1960s, the current American research effort in this area can be summed up in one word: negligible.

No U.S. government agency has serious plans for building a ship or submarine with magnetohydrodynamic (MHD) propulsion. A few groups, however, have built MHD "thrusters" in the laboratory. In the largest project,

researchers at Argonne National Laboratory in Illinois used a 21-foot-long superconducting magnet—30,000 times stronger than Earth's magnetic field—to propel water through an 18-inch-wide duct, simulating the action of an MHD jet in the open ocean.

Researchers at Newport News Shipbuilding Co. in Virginia and the Naval Underwater Systems Center in Newport, R.I., have conducted similar experiments, smaller in scale.

The conclusion from these studies? "There's no showstopper" that will make magnetic propulsion impractical, argues Michael Petrick, who led the Argonne team. The key to building an MHD-powered vessel, he says, is designing lighter and more efficient magnets. Although the Argonne experimental thruster was several times more efficient than those in Japan's *Yamato 1*, it nevertheless wasted about 60 percent of the force gener-



Electronic sensors monitor the temperature of superconducting magnets and other conditions inside the thruster compartment (above). Each thruster contains six individual water ducts (right).



ated by the magnet. Furthermore, the stainless steel magnet weighed 180 tons—far too heavy for a ship.

Another limitation of the technology is that MHD ships will not work in areas with significant amounts of fresh water, which does not conduct electricity as well as salt water. Thus it might be difficult for an MHD ship to dock at many major ports, says Mike Superczynski, an expert on superconducting magnets at the David Taylor Research Center in Annapolis, Md. Also, salt water would quickly corrode the electrodes in the thrusters, Superczynski argues.

Both the Argonne and Newport News Shipbuilding projects are now on hold, pending more government funding. "We've gone as far as we can go in the laboratory," says Newport News Shipbuilding's Rich Ranelone. "Our next step should be a demonstration at sea." Ranelone proposes installing a magnetic thruster on an existing research submarine.

He shouldn't get his hopes up. The Defense Advanced Research Projects Agency, which funds this type of work, doesn't have the money to keep MHD research afloat. "We've finished our program," says Captain Ted Rice, an undersea warfare expert at the agency. "There are too many other things we need to attack."

Navy brass aren't excited about MHD propulsion either, agree experts close to the service. "The Navy is not even vaguely enthused about the idea," says Alan Berman, a staff member at the Center for Naval Analyses in Alexandria, Va. The biggest potential drawback: The huge magnetic fields emanating from an MHD-powered submarine would make it easy for enemies to detect, even if it made no sound. An MHD-powered sub would also leave a trail of chlorine, created by the electrolysis of seawater. For now, it looks like the international race to build a magnet-powered ship has exactly one contender.—Robert Langreth

turned a laboratory curiosity into a full-scale moving boat.

Making it practical, however, is a bigger challenge. *Yamato's* thrusters, refrigeration systems, and twin 2,000-kilowatt diesel generators virtually fill the 98-foot ship, leaving room for a crew of only ten in a cramped cockpit. The equipment weighs 143 tons, or about 70 percent of the total vessel displacement of 204 tons. By comparison, the propulsion systems of current oceangoing freighters typically account for less than 10 percent of the total displacement.

The maximum efficiency expected from *Yamato 1* is less than 4 percent. The efficiency of current commercial ships ranges from around 22 percent for hydrofoils to 60 percent for cargo ships. And a first-rate sculler can propel himself along faster than *Yamato 1*, which has a top speed of only eight knots (9.2 mph).

For MHD propulsion to become practical, researchers will have to develop magnets that are much lighter and more powerful than current ones. *Yamato's* coils now generate a maximum magnetic field of four tesla. Imaichi thinks the magnetic field can be raised to 30 tesla within the next two decades, and that this improvement will result in an overall efficiency of between 22 and 23 percent. This, he says, is comparable to the current efficiency of hydrofoils. "An MHD ship can be competitive with that kind of ship," Imaichi says. But to date, the maximum steady-state magnetic field achieved using

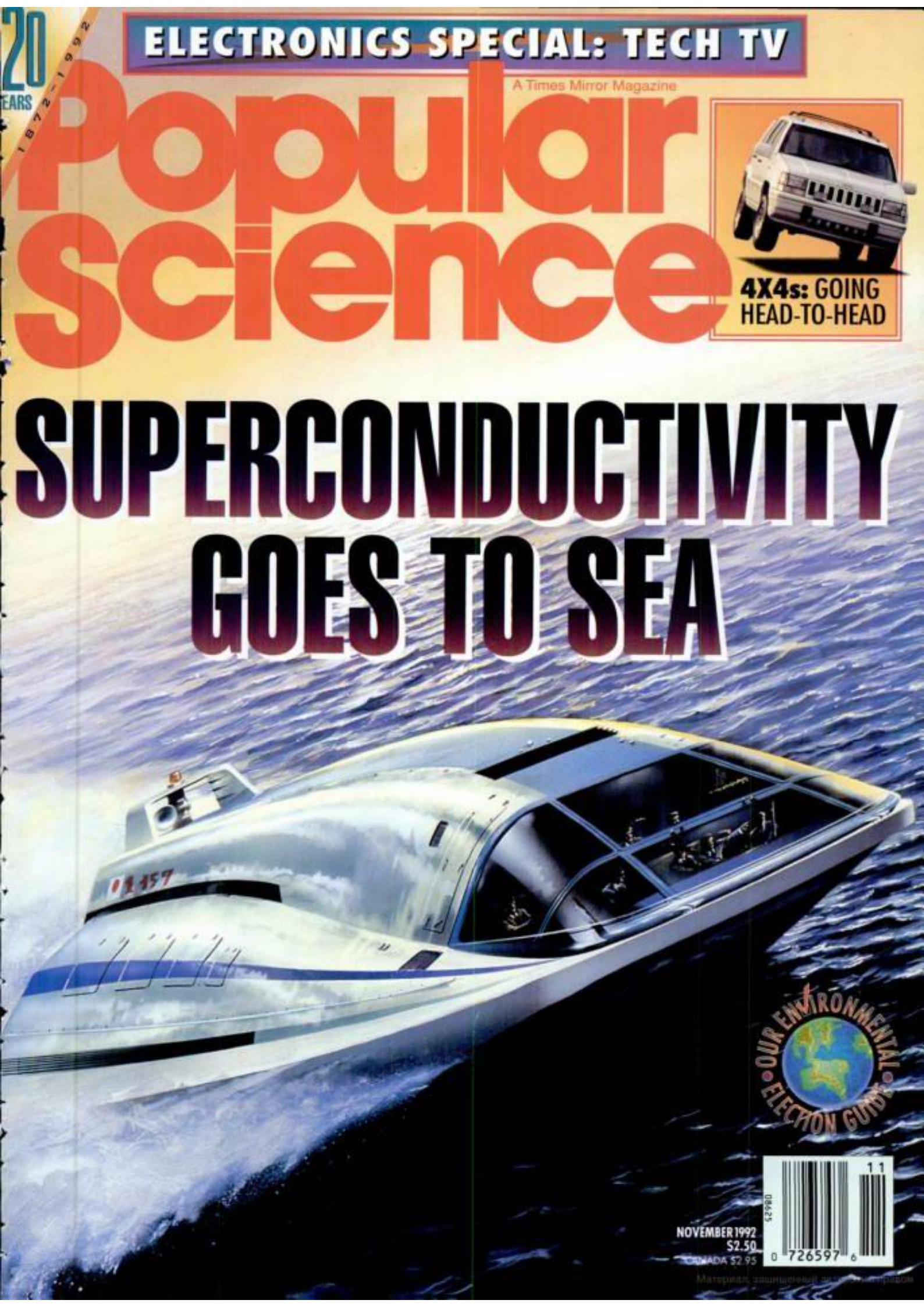
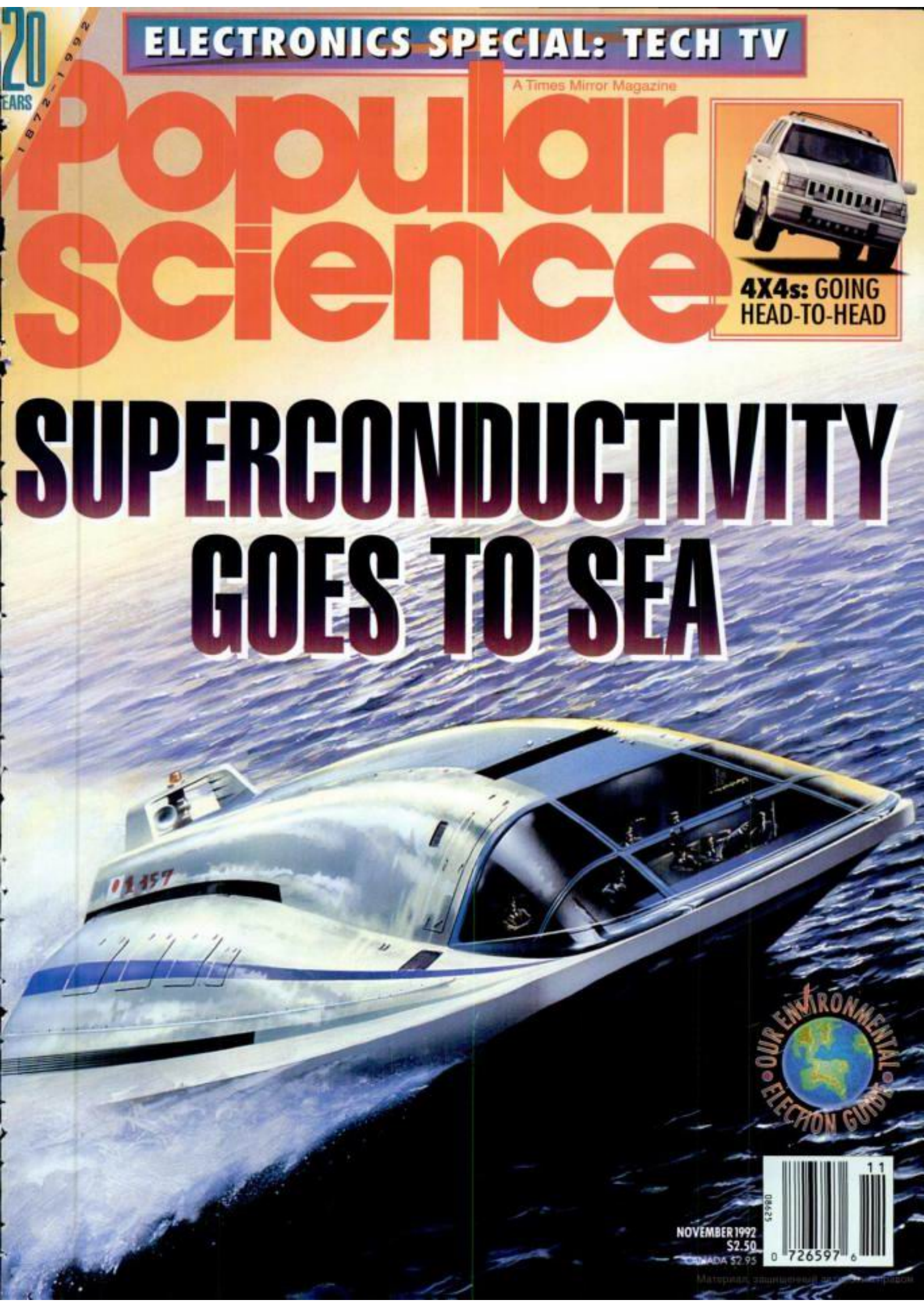
superconductors has been about 20 tesla.

Incremental improvements will come from using superfluid helium, which can cool the superconducting coil down to 1.8°K (-456.45°F), allowing increased current and thus a stronger magnetic field. Superconducting niobium-tin alloy filaments will also provide stronger fields, but the material is much harder to form into wires than the niobium-titanium alloy used in the present coils.

A leap forward could come with the refinement of new ceramic superconducting materials, which weigh as little as one-third as much as metal superconductors currently available. More important, with critical temperatures above 77°K (-321.09°F), the ceramics are "high-temperature" superconductors. This means they can be cooled with liquid nitrogen, which is less expensive and easier to use than liquid helium.

Taking these possible advances into account, Imaichi and other researchers have concluded that the ultimate efficiency of the technology will be somewhere around 50 percent, equivalent to the efficiency of current cargo ships. Hoping for the technological breakthroughs that will make MHD propulsion competitive with conventional ships, Sasakawa and his colleagues intend to build a second-generation MHD ship.

"It took 130 years for Watt's steam engine to be put to practical use on a ship," Sasakawa explains. "If you don't have dreams, you can't make progress."



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**4X4s: GOING
HEAD-TO-HEAD**

SUPERCONDUCTIVITY GOES TO SEA



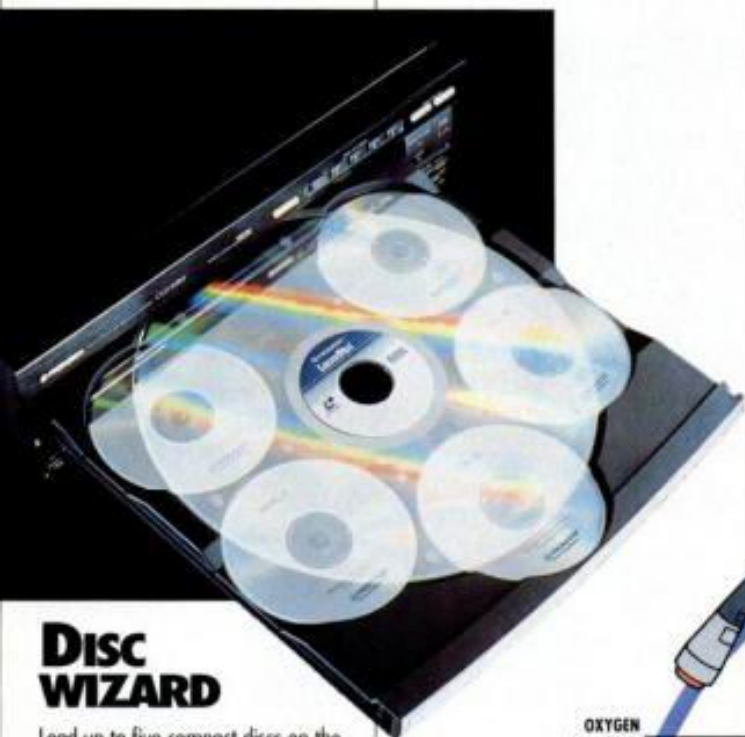
NOVEMBER 1992
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WHAT'S NEW

EDITED BY MARCELLE M. SOVIERO AND JUDITH ANNE YEAPLE

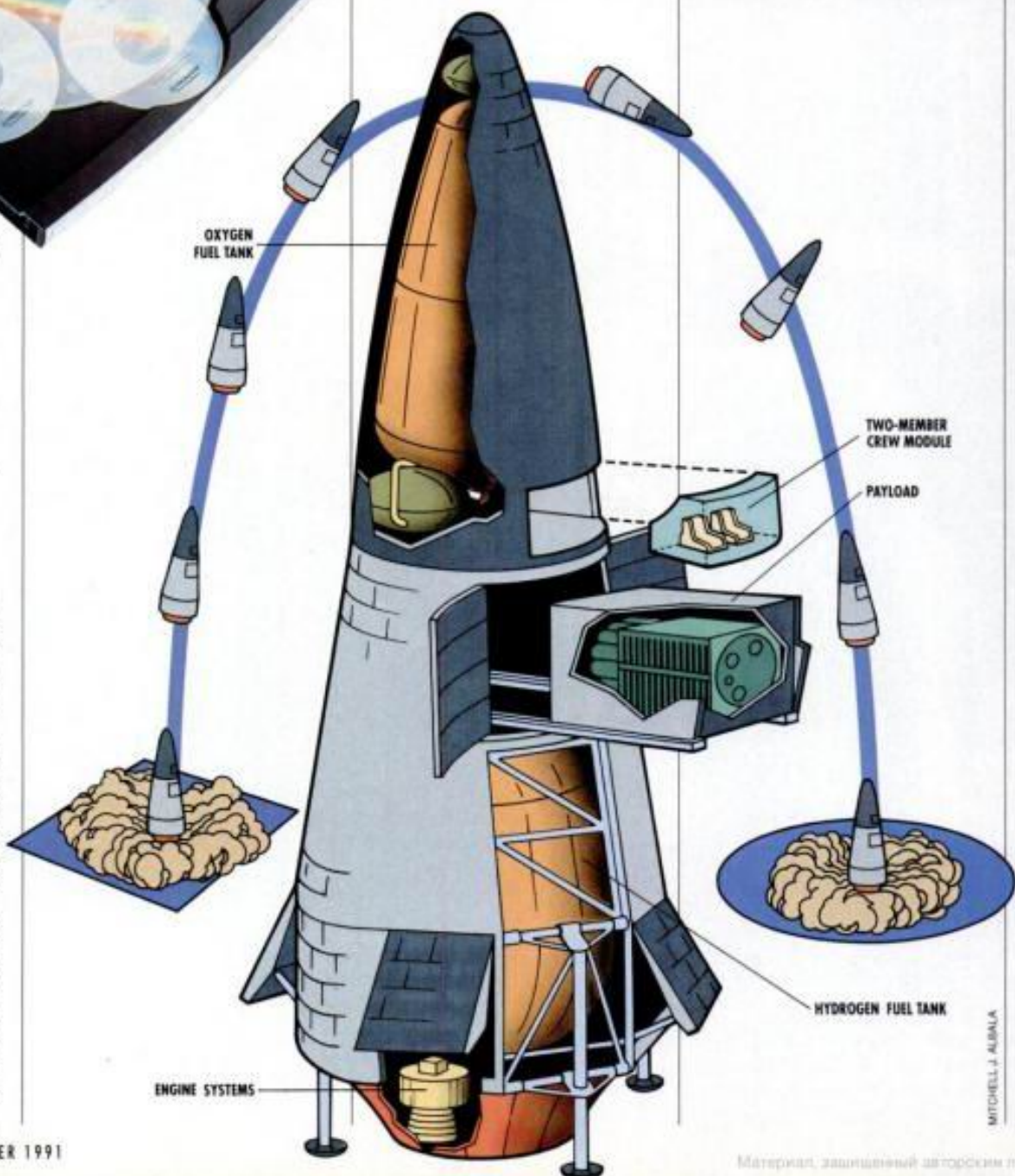


DISC WIZARD

Load up to five compact discs on the Pioneer CLD-M90's slide-out tray and a mechanical arm shifts selected discs from the tray rim to the center for playback. The \$700 machine also plays a videodisc that is placed on top of the CDs, displaying its playback and programming status on your TV screen. A new feature offers one-second "sound bites" during fast scans of videodiscs.

FAST TRACK TO SPACE

This Single-Stage-to-Orbit (SSTO) vehicle could fill the technology gap in Earth-to-orbit transportation. Using off-the-shelf components, the oxygen-carrying rocket could be less expensive and take less time to ready for flight than the space shuttle, and may fly years before the air-breathing National Aerospace Plane ("X-30," this issue). Sponsored by the Strategic Defense Initiative Organization, the reusable rocket is intended for commercial and military missions up to 14 days long, either with a two-man crew or guided remotely. It would take off and land vertically. A test flight is scheduled for 1993.



WASTE NOT WATER

The S35 Waterwatcher connects to a water pipe that supplies your dishwasher or shower to measure water usage in gallons, liters, or cubic feet. A S40 version attaches to your garden hose, or a S60 version can be plumber-installed on the water main. The unit's display provides monthly comparisons. Waterwatcher, 1219 Morningside Dr., Suite 50, Manhattan Beach CA 90266.



Boarding a sleek bullet-nosed train in Dallas, a businessman sets out on his daily 245-mile commute to Houston. The trip will take just 90 minutes aboard hushed, comfortable cars hurtling between the cities at speeds up to 200 mph. At the same time, a family of vacationers bound for Walt Disney World is being whisked from the Orlando International Airport in Florida to a station just outside the amusement park. They're riding a magnetically levitated train that reach-

es a top speed of 250 mph for much of the 13.5-mile, 6.5-minute trip.

Such high-speed, earthbound journeys are still only dreams for American travelers. But transportation projects now under way should change that. Both the Dallas-to-Houston and the Orlando scenarios will be snapshots of daily life in the mid-1990s—if all goes according to schedule. Florida recently approved a plan to build a magnetically levitated, or maglev, train system that would begin operating in 1996, making it the first commercial train of its kind in the world. Texas, meanwhile, has au-

thorized an international team headed by U.S. construction giant Morrison-Knudsen Corp. to build a statewide, steel-wheel-on-rail system based on the high-speed French TGVs (*trains à grande vitesse*—the fast trains). The Texas trains are slated to begin running in 1998.

Steel-wheel trains, like the one being planned for Texas, roll along rails like conventional trains, but use powerful electric motors, better suspension systems, computerized signaling systems, and lighter, more aerodynamic cars (see Safety and Comfort on Steel Wheels). These improvements, coupled with long stretches of flat, uninterrupted track, enable steel-wheel trains to reach speeds of greater than 300 mph. For reasons of passenger comfort and track maintenance, though, 170 to 210 mph is typical for commercial service.

Maglev trains, on the other hand, bear little resemblance to conventional trains. Despite the fact that they're often grouped with other high-speed rail

Gridlock on the roads and "winglock" in the skies spur U.S. development of maglev and other new high-speed trains that travel as fast as planes.

RAPID RAILS

BY CHRISTOPHER O'MALLEY

**Popular
Science**
JUNE 1992



systems, maglev trains don't ride on rails at all. Instead, they literally ride on a cushion of air, suspended above and propelled along an elevated guideway by the attractive or repulsive forces of powerful magnets. Linear electric motors built into the guideway generate a "traveling" magnetic field that pulls the vehicles along or an on-board motor induces propulsion forces in a metal guideway plate (see *Maglev Gathers Speed in Japan*). This technology enables maglev trains to easily attain very high speeds even over short distances, as the proposed 250-mph Orlando system illustrates.

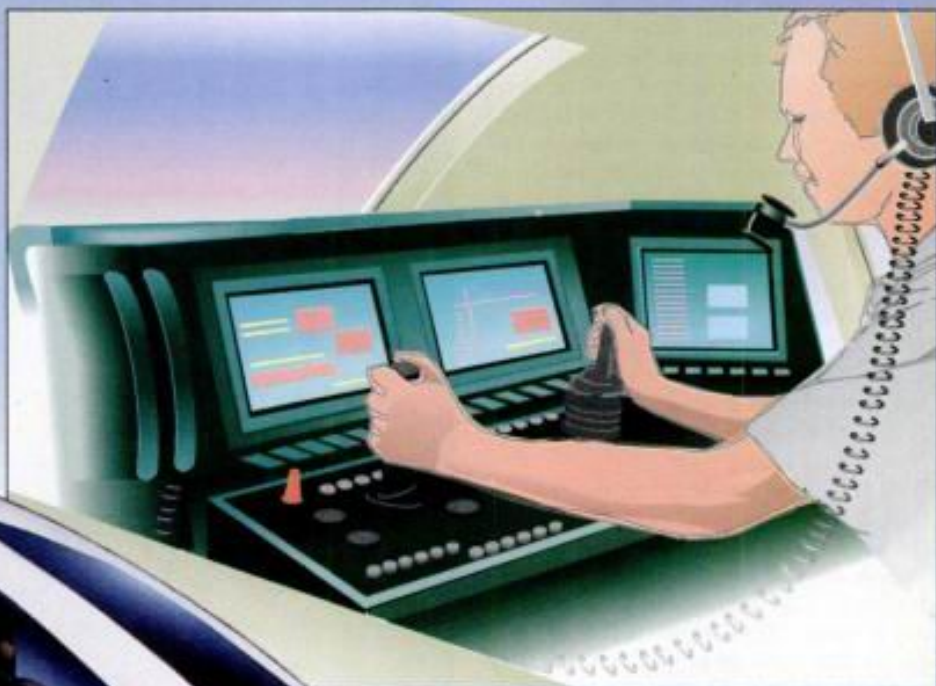
Proponents of high-speed trains believe the Orlando and Texas projects will be the first of many rapid rail lines in the United States, serving as showcases for the technology and catalysts for other efforts. Indeed, a number of states are considering proposals to develop high-speed trains (see map). Skeptics say that none of these costly projects—including the \$622 million

Orlando and \$6.8 billion Texas systems—are funded yet, and neither the federal nor state governments are inclined to pick up the tab. Supporters, however, are undaunted. "The money is there, and it's there through private investment," insists Bob Neely, executive director of the Texas High Speed Rail Authority in Austin.

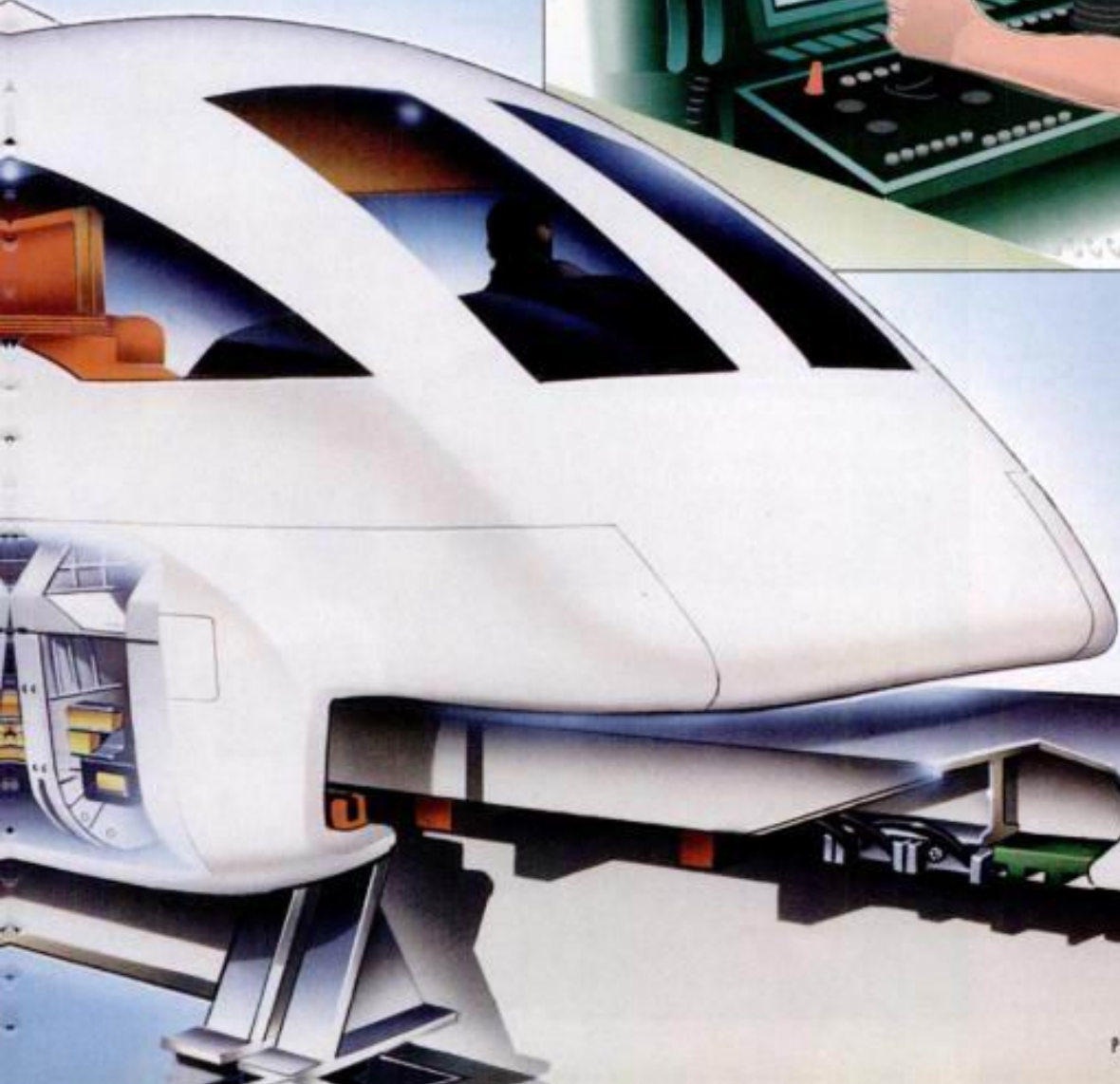
There is reason for optimism. After more than a decade of watching France, Germany, Japan, and others build high-speed rail lines, interest in seeing United States high-speed trains go into service is peaking. American technology titans such as Grumman Corp., Martin Marietta, General Motors, McDonnell Douglas, and

Bechtel Corp. are all promoting the development of U.S. high-speed rail systems, as are many of Europe's largest technology companies. These and myriad smaller advocates have boosted membership in the High Speed Rail Association, an influential umbrella group based in Pittsburgh, from fewer than 500 in 1990 to 1,200 today and climbing.

There is also growing bipartisan political support in many state legislatures and Congress for building high-speed trains. As part of a new six-year transportation bill passed last November, Congress adopted provisions that make it easier for states to put high-speed trains alongside high-



Transrapid 07, the latest maglev model developed by a German consortium, is attracted upward toward a guideway by on-board magnets—powered by batteries for extra safety. Coils along the guideway propel the vehicle. Computers in the engineer's cabin (above) communicate with controls along the vehicle's path.



MARC EROSEN

IAN WORTH

**Huge new jetliners
carrying 600 to
800 passengers
could be flying
within a decade.**

**BY BILL SWEETMAN
AND STUART F. BROWN**

Aeronautical engineers toiling at computer workstations in the United States and Europe are conceiving a new generation of gigantic airliners. The designers aren't just dreaming up pretty pictures for the next corporate annual report. Commercial airlines—their customers—want to know how soon they can begin flying megaplanes on the booming routes to the Asia-Pacific region.

Airbus Industrie, Boeing, and McDonnell Douglas, the world's biggest aircraft manufacturers, have all sketched stout double-decker jets that resemble 747s that have just eaten a billion cheeseburgers. At least one of these leviathans could be in service by the year 2003.

At the same time, an advanced brainstorming group at McDonnell Douglas is working on something completely different: a "blended wing

body" megaplane. Combining elements of a bat-like flying wing with conventional slender wingtips, the stunning craft promises unprecedented fuel efficiency.

Traffic-jammed Asian airports have created a market for these super-jumbo airplanes. In bustling commercial hubs like Osaka, Taipei, Hong Kong, and Singapore, the airports are carpeted with 747s during peak flying hours. According to the International Air Transport Association, seven of the 10 busiest Asia-Pacific airports will begin to run out of space this year. Oval-bodied double deckers designed to fit existing taxiways and terminal gates are the only way to move more people through airports that are approaching runway gridlock.

Singapore Airlines (SIA) would order megaplanes today, if it could. "How many we need is a function of when the aircraft is available," says managing director Cheong Choong Kong. "The

MEGAPLANES



further down the road we look, the more we need." When SIA talks, plane manufacturers listen. A fledgling airline 20 years ago, it has grown into a profitable intercontinental powerhouse that usually trades in its aircraft for new ones when they are less than seven years old.

Airbus, the European airliner consortium, sees 2003 as the earliest service-entry date for its A3XX megaplane design. The plane will need a range of at least 8,500 miles to provide nonstop service on long routes such as London-to-Singapore. And the A3XX will have to be very efficient for airlines to meet its \$200 million-plus price tag. Airbus Industrie's goal is an aircraft that carries 30 percent more passengers than a 747 but costs only 12 to 13 percent more per mile to fly. Larger versions also could be built.

McDonnell Douglas has shown a classic-looking megaplane concept called the MD-12. Like the A3XX, it is

a four-engined craft with a full-length double deck. The MD-12 holds a relatively modest 510 passengers, but the company is known to be studying larger versions. Boeing has released a 600-seat megaplane concept code-named the New Large Airplane (NLA), which could also be built in a stretched version carrying more than 700 passengers.

A major struggle for designers is tailoring the dimensions of these big double-deckers to the space available at airports. The megaplane's wingspan and length must be limited so it doesn't intrude on adjacent terminal gates when loading and unloading. Landing gear location is dictated by the width of taxiways, and the need to make sharp turns at junctions.

The A3XX design follows a path of careful compromise through this thick-et of constraints. It can seat 530 passengers in a three-class long-range layout, and up to 840 in high-density



configurations such as those used for Japanese domestic flights. The wings of the A3XX span 253 feet—41 feet more than Boeing's current 747-400 model—and thicken where they join the fuselage to make room for the main landing gear. Aerodynamic purists would like to reduce drag by using a longer and narrower wing spanning almost 270 feet, but Airbus studies suggest that 260 feet is about the upper limit for most airports. Folding outer wings will be offered, if airlines want them.

An aircraft of this size can use the same engines and nacelles as the existing twin-engine Airbus A330, so that development costs will be reduced. Boeing sees similar savings from powering the NLA with four of the large turbofans used on its new 777 twinjet.

The practical limit on fuselage length is also about 260 feet, giving designers two choices—a very wide body or two decks. Airbus looked at a flat-bodied configuration called a "horizontal double-bubble," which consisted of side-by-side cylinders blended together. But it was heavy, and the width of the body ate into the limited span available for the wings. Instead, Airbus designed an oval two-deck body, the same solution chosen by the Boeing and McDonnell engineers.

Dual decks work well for big aircraft. Though a cylinder is the lightest and strongest shape for an airplane's pressurized passenger compartment, an ultra-wide single-deck design leaves lots of space above and below the cabin. The airline can fill the "basement" beneath the floor with baggage and freight, but the upper half is inaccessible. Pinching the circular cross section of the fuselage into an oval makes room for an upper deck in the otherwise wasted "attic" space.

No law of physics says an airliner has to be an aluminum tube with wings and a tail. Why not a graceful, giant bird? That's the shape of the utterly unconventional blended wing body (BWB) megaplane evolving on computer screens at the advanced transport aircraft development division of McDonnell Douglas in Long



The McDonnell Douglas MD-12 megaplane concept calls for double passenger decks running along most of the length of the fuselage.

Beach, Calif. Major efficiency benefits promised by the radical design have got engineers there excited.

Calculations show that an 800-passenger, double-decker BWB with a 7,000-mile flying range would be 13 percent lighter and consume 31 percent less fuel than a conventionally shaped megaplane cruising at the same 560-mph speed. On a 6,500-mile flight from Los Angeles to Sydney, Australia, for example, the savings would add up to 12,000 gallons of jet fuel.

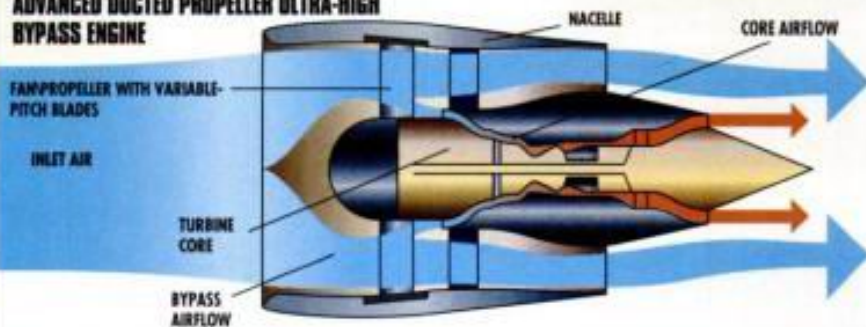
The BWB idea is a hybrid combining elements of a pure flying wing like the Northrop B-2 stealth bomber, and traditional slender-winged airplanes. It inherits valuable traits from both parents. "The way to evaluate an airplane is to look at its weight, its surface area, and its wingspan," says BWB configuration designer Blaine Rawdon. "You want low weight for obvious reasons. Small surface area—or wetted area—means less air-friction drag, and wide wingspan gives you low vortex drag, the losses that occur due to vortices forming at the wingtips. Everything came out nicer as we converged on this shape."

Deep-bellied and airfoil-shaped, the big bird's centerbody is a "spanloader" design that generates part of the airplane's lift while providing a large interior volume for passengers, fuel, and cargo. Stresses are reduced by distributing aerodynamic lift and the weight of the payload over this large area, which can be built from lighter, less expensive structures. "When all the dust settles, you buy airplanes pretty much by the pound," says Robert Liebeck, leader of the BWB team. An eminent wing specialist and a senior McDonnell fellow, he occupies the industrial equivalent of an endowed university chair.

Winglet-tipped, tapered outer wings for the BWB were borrowed from the conventional MD-12 megaliner being developed by another design team at

POWER FOR THE BLENDED WING BODY

ADVANCED DUCTED PROPELLER ULTRA-HIGH BYPASS ENGINE



A trio of 70,000-pound-thrust advanced ducted propeller (ADP) engines being developed by Pratt & Whitney would power the blended wing body. The fuel-efficient ADP is an ultra-high bypass design that uses a huge, multibladed front fan to push most of the inlet air around the engine's turbine core, while a small flow passes through it and combusts with jet fuel. The ratio of bypass air to turbine air is 22:1.

Today's most efficient fanjets use a bypass ratio of 10:1.

The fore-to-aft slice of the blended wing body's airfoil-shaped center section shows the transition of smooth airflow into turbulence, which is gobbled up by the engine inlet duct. Efficiency of the ducted propeller increases in the slower-moving turbulent airflow. Altering propeller blade angle creates reverse thrust during landings.—S.F.B.

The WHAT'S NEW magazine

MAY 1986

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THE
ELECTRONIC
REVOLUTION
IN POWER
STEERING

Popular Science

Coast to coast in minutes:
Engineering next-generation

SPACE PLANES



Low-cost word processors for your home
New airport X-ray spots invisible terrorist weapons



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Spurred by advances in engine design, materials technology, and supercomputing, a radical new kind of airplane is being developed. Like the concept craft from Lockheed at right, it could flash through the fringes of space at hypersonic speeds.

Space plane —coast to coast in 12 minutes

By JIM SCHEFTER

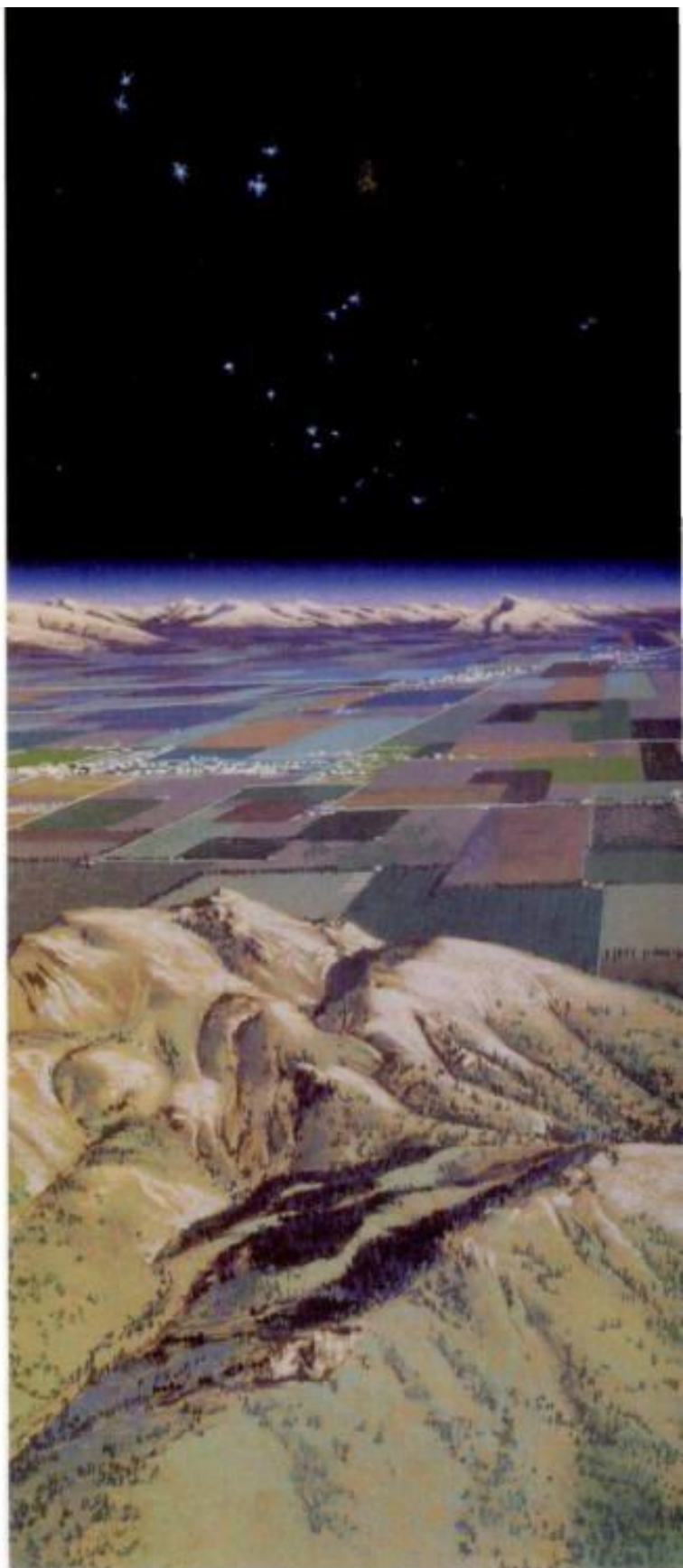
It's 10 a.m. at New York's Kennedy Airport: "Global Airways flight 2005 now departing from gate 11," says a voice over the PA system.

At Los Angeles International Airport, it's 7:42 a.m. when the following message is heard: "Global Airways flight 2005 now arriving at gate 17."

Elapsed time from coast to coast: 12 minutes; gate to gate: 42 minutes. That's 15 minutes climbing, 15 minutes descending, and 12 minutes in between. Add another 20 to 30 minutes for the en route cruise at altitudes more than

30 miles high, and the same flight could have landed in Hong Kong or Sydney, Australia.

That incredible aircraft, cruising just below the edge of space at speeds between Mach 15 and 25, is the aerospace plane, or transatmospheric vehicle. It's no engineering pipe dream. President Reagan, in his February State of the Union address, said "we are going forward with research" on the visionary plane that has been dubbed "a new Orient Express." The National Aeronautics and Space Administration (NASA) and the Pentagon, already backed by a budget commitment from the White House, expect to begin flying an X-type (experimental) transatmospheric research plane





within five or six years. It will fly somewhere between Mach 12 and Mach 25. The plane won't carry more than a single test pilot. But it may begin carving a path through the fringe of space for commercial airliners—and perhaps orbiting transports—of the 21st century. As last month's "Scramjets" article indicated, a Mach 5 or 6 plane could be attainable with air-turbo-ramjet engine technology, but present thinking is to leapfrog that stage.

Turning the dream of hypersonic flight into reality, say experts involved in the program, is possible because of recent breakthroughs in both engine and materials technology and in the use of supercomputers. I talked with the

key people pushing for aerospaceplane development in the U.S. and discovered that both research and development and the government's quiet planning are well advanced.

At the same time, the British government's spaceplane program, less ambitious than ours, moves quietly forward under tight security wraps. It is called HOTOL (for horizontal takeoff and landing). In February, the Trade Ministry authorized \$4.1 million more for HOTOL studies.

"We have a whole new generation of materials, propulsion systems, and large computers under development or already in use at various research facilities," a highly placed

Continued





Shuttle-like Rockwell aerospaceplane (above) uses a two-stage system: A reusable launch undercarriage with its own engine assists takeoff, then drops away. Needle-nosed McDonnell Douglas concept (above right) is shown in Earth orbit, 1,200 nautical miles up. The strategic/reconnaissance aircraft could fly at Mach 12. Boeing's transatmospheric vehicle design (below left) is carried, with its massive fuel tank, atop a 747 before release into hypersonic flight.

White House expert, who asked not to be named, told me. "All these are reaching maturity, and there is the potential for integrating them into a flying vehicle. But the reality is that there is great difficulty in making the formal decision. It's all tied in with the budget process. The spaceplane will fly so long as it doesn't inhibit space-station development."

There are, however, some negative voices in the aerospaceplane chorus. Some critics believe that we should be aiming first at an intermediate supersonic passenger plane,



such as the 1,700-mph second-generation Concorde the French are interested in building. One naysayer is industry expert John Steiner, who retired in 1983 as a vice president of Boeing and then served as chairman of the White House Aeronautical Policy Review Committee. He believes that airlines would go for a superfast supersonic aircraft to service the Pacific Rim, but that the real interest in hypersonic aircraft is military, not commercial. And John Pike, of the Federation of American Scientists, has said that the aerospaceplane makes sense for the backers of the Strategic Defense Initiative (the Star Wars plan) because it would lower the cost of space launches. But he questions whether there is really any other economical use for it.

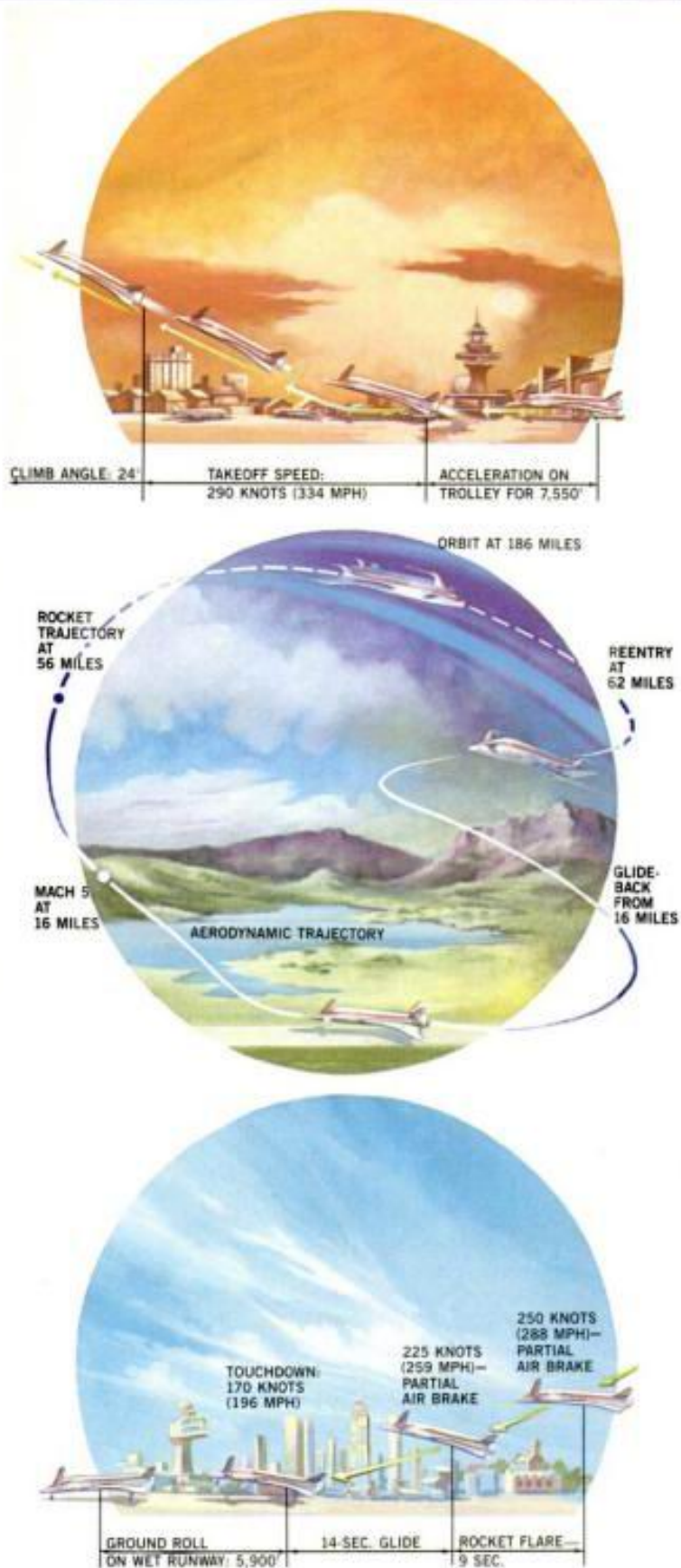
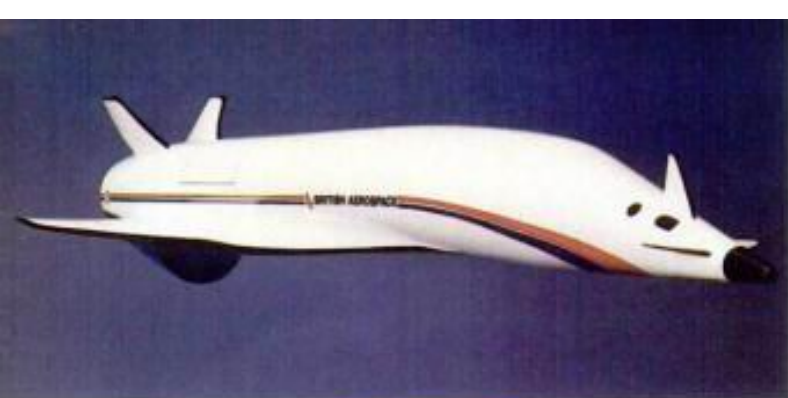
Nevertheless, much of the basic research needed to go ahead with a hypersonic research aircraft is in hand, most of it done at NASA's Langley Research Center, Virginia, which has quietly spent \$4 million to \$5 million a year on hypersonics for more than a decade.

"We've made sustained and steady progress," said Lana Couch, NASA's manager of the hypersonics program. "But we have several years of work ahead before the decision makers can choose a system and decide to develop it. By 1995 we will have laid the broad technology base that will make it possible for this country to build an operational hypersonic aircraft."

The U.S. aerospaceplane concept differs markedly from the British design. The basic version would be powered by scramjets, fly just below the edge of space at speeds higher than Mach 15, and operate from traditional runways. A more advanced plane would add rocket power to give it the extra kick needed to go into orbit from its cruising altitude.

Scramjet technology is a major key to the U.S. effort. "We're not talking about ramjets burning methane to reach Mach 5 or 6," said the White House expert. "They don't meet the demands of the spaceplane regime, and there's no

Continued



way those planes are going to fly out of the atmosphere."

Scramjets will be fueled by hydrogen and will draw their oxygen from outside air. Research at Langley already shows that scramjets can outperform rockets by a factor of 10 at speeds above Mach 6. But much detailed development work remains to be done.

And now, for something completely different

In contrast, the British HOTOL is to be powered by air-breathing rockets fueled by liquid oxygen and hydrogen. Those engines are a breakthrough in rocket technology, since they would draw oxygen from the atmosphere during much of the climb toward either cruising altitude or orbit. That reduces the amount of propellant that must be carried on board and, according to information released by British Aerospace Corp., "permits the use of wings to optimize the initial flight trajectory after takeoff from a standard runway." Details on how the revolutionary rocket engine works, however, are a closely held British secret.

HOTOL also would use a simple trolley, which parts company with the craft at liftoff, for its takeoff role. Its design calls for a gliding shuttle-like landing on a lightweight undercarriage. It would be a relatively small spaceplane, with a payload of just seven tons—less than one-fourth the shuttle's capacity.

So far, the British government has not announced an operational date for HOTOL. It is called simply "a launch vehicle for the 21st century." Initial missions would be unmanned, intended to place satellites in orbit. But the British envision an airline-type passenger module that could be placed into its cargo bay for piloted trips from London to Sydney taking little more than an hour.

"We respect the British as researchers," the White House expert told me, "but there's a real question about whether they have the wherewithal to pull it off."

No such question exists, at least in the minds of its advocates, about the U.S. aerospaceplane. The development program is run jointly by the Air Force, Navy, and NASA, and is headquartered at Wright-Patterson Air Force Base, Ohio. It has strong military overtones, particularly in terms of the aerospaceplane's potential for servicing orbiting lasers as part of the president's Strategic Defense Initiative.

"It's a single national program," said SDI spokesman Brig. Gen. Robert R. Rankine. "The phase that begins in 1986 attacks the critical technologies—propulsion, structure and materials, and aerodynamics."

The latter is particularly crucial. Research already completed shows that an aerospaceplane's shape is a vital element in making scramjet engines operate efficiently. The plane's underbody must funnel air into the engine at exactly the right velocity and temperature. If the fuselage is designed properly, air heated to more than 4,000 degrees F by the plane's forward motion will be slowed slightly, then funneled into the engine. Air temperature alone will ignite the hydrogen fuel.

Much of the development yet to be done involves computational fluid dynamics—the analytical field that studies how fast-moving fluids such as air act under conditions of high temperature and pressure. Only the advent of supercomputers makes the complex and lengthy calculations needed to design an aerospaceplane realistically possible.

"It's a real challenge in terms of engine integration with the airframe," Rankine told me. "Supercomputers allow us to do complete calculations of the airflow for both internal and external aerodynamics. We can find solutions that

(Continued on page 116)

British Aerospace HOTOL would take off from a rolling trolley, use secret air-breathing engines to loft a seven-ton payload into orbit, and land much like the shuttle (left).



A cross section of the first drift and access pit shows the borer, the unloaded tunnel liners, and the earth-removal cars.

below us and had already been filled with concrete. At two o'clock, spaced every 300 feet, hung a series of rigidly mounted six-by-eight-inch steel plates, each with a 1/4-inch hole through it.

"That's a laser-guidance system," Hardy explained. "The beam, aimed from the entrance, is pencil-thin but tends to widen slightly. For accuracy we want a narrow beam, so at intervals we condense it through these holes."

Though the tunnel's crown will be but 110 feet below the crest of the ridge, the pressures on the subterranean crust are unique and treacherous. Ice-age glaciation that towered some 4,000 feet produced locked-in horizontal stresses up to three times the pressure of material overlying the tunnel. As the soil is removed, the stresses unlock and bear from all directions upon the excavation, hence the obvious wisdom of this ring-of-tunnels technique—in engineering parlance, the "stacked-drift" method. Small tunnels drilled sequentially and fitted with modest liners can handle the stresses. When each is filled with concrete and the ring is closed and excavated, the omnidirectional pressures will compress the units into an integral, super-strong tube.

Engineers chose a horseshoe shape for each drift because each one will fit neatly against the one next to it. Another useful feature: Its more-than-full-circle cross section affords maximum working space.

At the controls

At the conveyor we ducked under the belt, which ran between roller-footed straddling legs. We squeezed past the liner-installing machinery and entered the "shield"—a giant armor-plated piston that carves the earthen cylinder. The shield is a tunneling machine with the same cross section as the desired drift. Its walls maintain the excavation shape until a liner is placed.

The 75-foot-long conveyor we had just passed was gimbaled to a ring that revolves when necessary to keep the operator level as the shield's backhoe rotates to dig. Hardy nodded an invitation, and I shoehorned into the operator's seat. Simple controls, I thought, for such an awesome machine. The machine's digging arm at the tunnel face bristled with single upper and lower teeth, which are maneuvered by only two joy sticks. The only other items on the main panel were a master switch, a conveyor switch, and warning lights.

Above me I noticed a white plate bearing a target grid. "When the laser beam centers on the grid, we're on course," Hardy said. "When it's off-center, we correct our course."

"How?" I asked.

Hardy pointed. Under my left elbow was a panel with a horseshoe pattern of 12 switches to operate hydraulic cylinders around the shield's skirt. Together they push off from the last liner section, shoving the shield through the ridge. After every four feet of progress, liners are set and cylinders repositioned, and digging resumes.

To minimize noise and disruption of the neighborhood, the ridge penetration starts from vertical access pits 100 feet in diameter, one at each end of the tunnel, sunk to a level even with the bottom of the first drift. The pits are circular and ringed with poured-in-place concrete columns. The tunnel-boring machines, or shields, push off from the west pit, exiting in the east pit—the excavated soil is hoisted and trucked from the west, or starting, pit. After each drift is bored, a shield is trucked back to the west pit to start again.

At the tunnel's completion a portion of the wall of each pit will be removed—this will be the entrance of I-90 to the tunnel. The remaining semicircle of columns will be refurbished to serve as retaining walls, and above each en-

trance massive stabilization slabs will prevent landslides.

The Mount Baker Ridge tunnel will be the world's largest-diameter hole through loose material. Though the plan is clever, technical risks exist. At this writing, nonuniform pressures have bent the initial drifts slightly out of line—following the passage of the shield and after the drifts were filled—which underscores the difficulty of coping with the ridge's weird pressure patterns. Another problem was the deformation of liner sections in places, which broke the bond between the liner and its concrete core.

Solutions proposed for the problems include deflecting subsequent drifts to compensate for the out-of-line ones (which, as it happens, will be below the tunnel grade level anyway). And where liners have separated, technicians will bore holes through the liner walls and fill any voids with grout fed in under pressure.

The challenge is awesome, but the engineers of the project are certain that their ring of tunnels will tame the ice-age legacy.

123

Tunnel statistics

Length	1,500 ft. (including access pits/entrances)
Inside diameter	63 ft.
Outside diameter	82 ft.
Number of horizontal drifts	24
Drift diameter	9 ft. 6 in. (horseshoe shape)
Volume of excavation for drifts	84,500 cu. yds. (clay, silt, sand)
Concrete fill for drifts	73,800 cu. yds.
Number of precast liner segments	38,130 (five for each ring)

Lower level (two reversible lanes)

Minimum width	40 ft. 9 in.
Minimum height	15 ft.
Division	Two 12-ft. lanes, two 8-ft. shoulders

Middle level (westbound traffic)

Minimum width	54 ft. 10 in.
Minimum height	18 ft.
Division	Three 12-ft. lanes, one 10-ft. shoulder, one 6-ft. shoulder

Upper level (for bicycles and pedestrians)

Width	15 ft.
Minimum height	10 ft.

Seattle superhighway gets a *tunnel of tubes*

Normal tunneling techniques won't work in sand, mud, or loose soil. So engineers devised an ingenious technique for digging through Seattle's Mount Baker Ridge. Earth-boring machines are digging a series of small tunnels that will be filled with concrete to form a large tube. The tube will then be excavated for underground roadways.

By **KENNETH BROOKS**

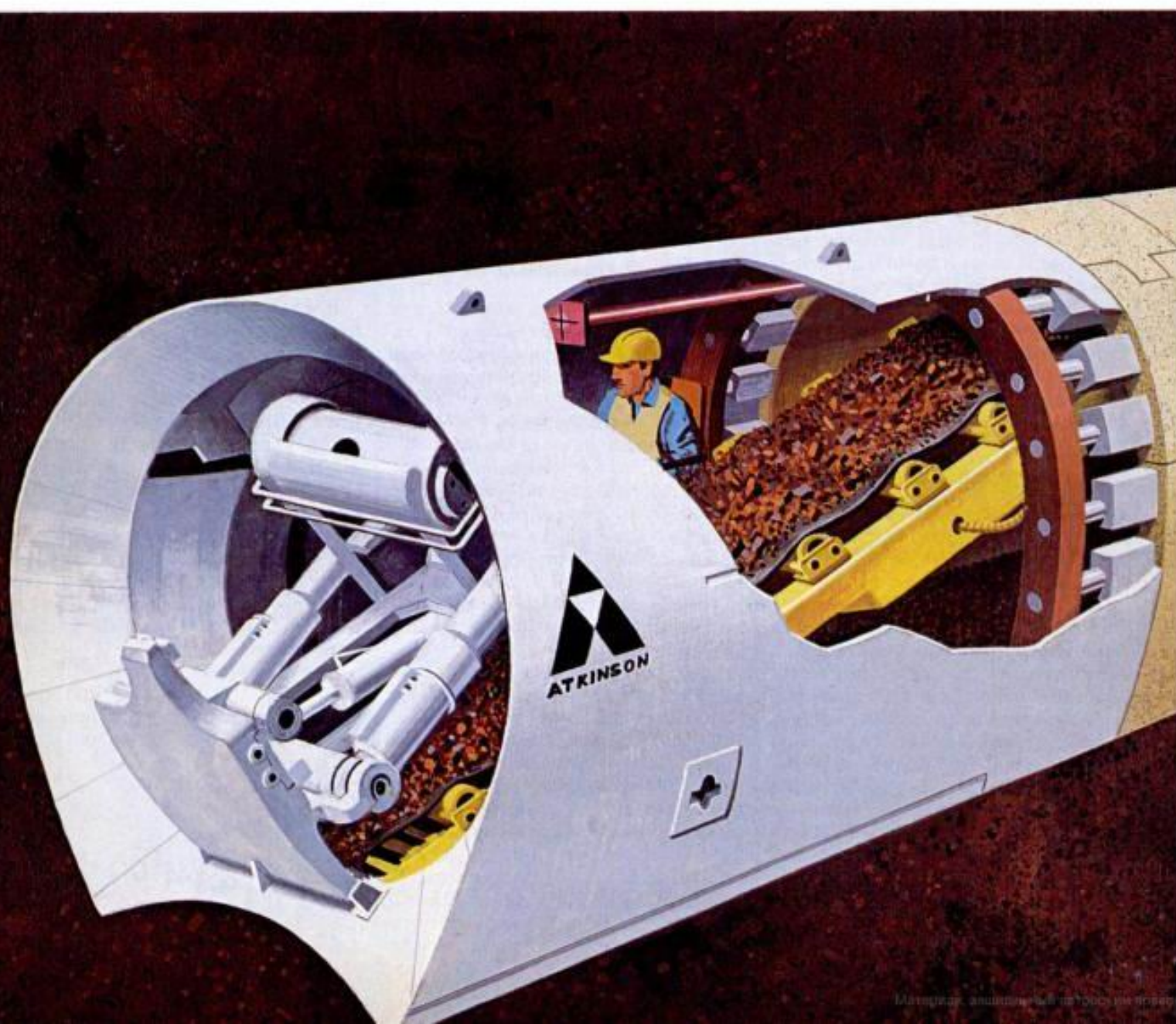
Illustrations by Adolph Brotman

Here's the problem: A superhighway tunnel must be cut through a glacial ridge. But the ridge is not a hard rock formation that can be

predictably churned through; it's a super-compacted mound of clay dotted with boulders, silt, and sand pockets—soil that tends to backfill a tunnel as fast as it's dug.

The Washington State Department of Transportation's solution is inge-

nious and daring: Reverse the order of construction. That is, penetrate the ridge with a ring of 9½-foot tunnels, each lined with precast concrete sections, then fill each tunnel with concrete. When the ring of tunnels is whole, excavate the dirt within the



tunnels and then construct roadways.

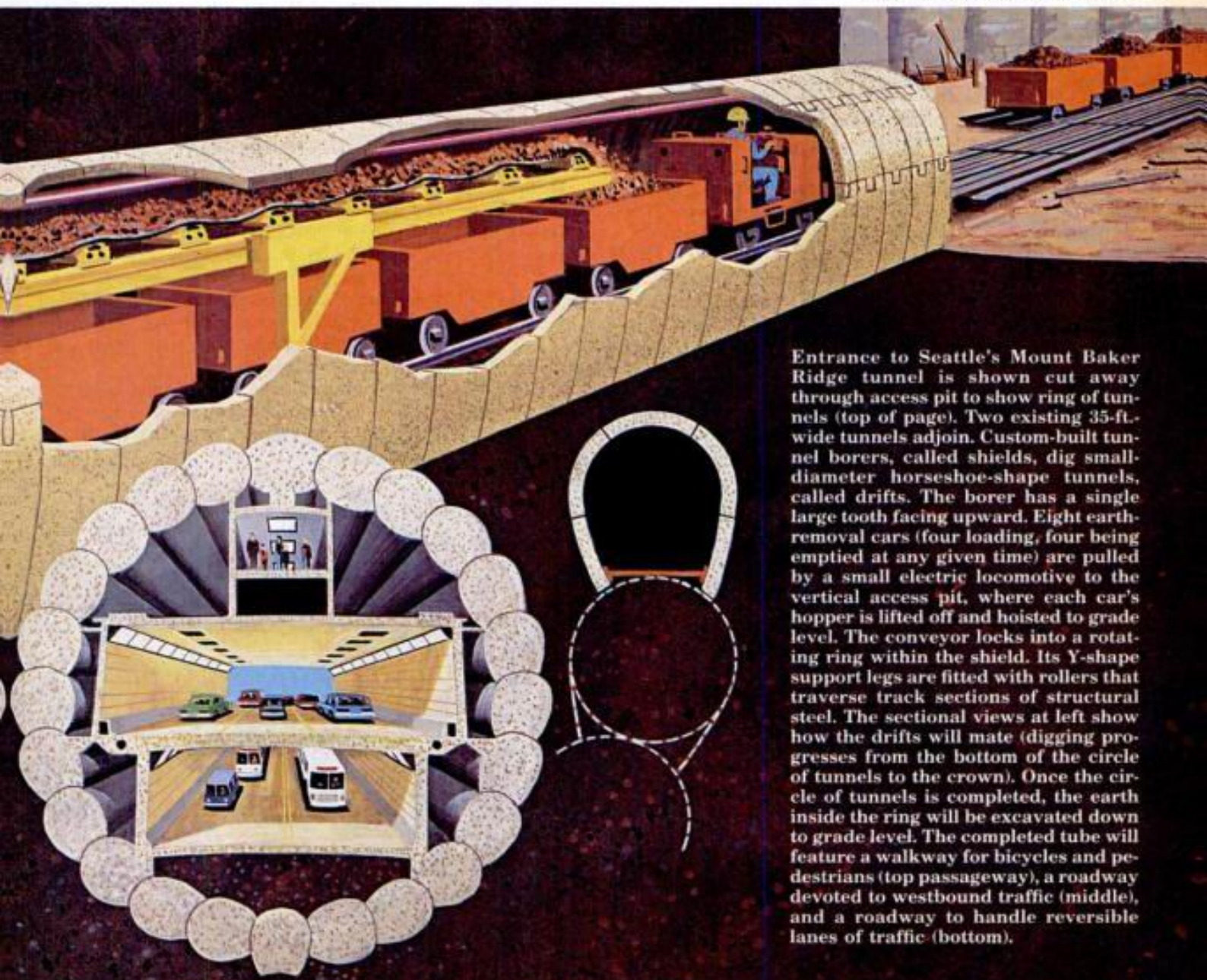
The 1,500-foot tunnel is the western terminus of Interstate 90, less than a mile from its junction with Interstate 5. Completion is scheduled for the summer of 1986. It will run through Seattle's Mount Baker Ridge, which separates downtown from suburban Lake Washington. I visited the site of the \$110-million project recently to see how engineers are confronting this unique challenge.

Between shifts, escorted by Washington State DOT project engineer Ollie Hardy, I explored the half-finished No. 2 "drift" (the term used by engineers to refer to one of the small tunnels that will encircle the principal passageway). Beneath bare bulbs we trod a narrow-gauge track. "Just like a mine," I thought—except that this mine was lined with precast concrete sections. At eight o'clock on the circumference lay the curved shoulder of the so-called "invert" drift, which lay

Continued



WASHINGTON STATE DEPARTMENT OF TRANSPORTATION



Entrance to Seattle's Mount Baker Ridge tunnel is shown cut away through access pit to show ring of tunnels (top of page). Two existing 35-ft.-wide tunnels adjoin. Custom-built tunnel borers, called shields, dig small-diameter horseshoe-shape tunnels, called drifts. The borer has a single large tooth facing upward. Eight earth-removal cars (four loading, four being emptied at any given time) are pulled by a small electric locomotive to the vertical access pit, where each car's hopper is lifted off and hoisted to grade level. The conveyor locks into a rotating ring within the shield. Its Y-shape support legs are fitted with rollers that traverse track sections of structural steel. The sectional views at left show how the drifts will mate (digging progresses from the bottom of the circle of tunnels to the crown). Once the circle of tunnels is completed, the earth inside the ring will be excavated down to grade level. The completed tube will feature a walkway for bicycles and pedestrians (top passageway), a roadway devoted to westbound traffic (middle), and a roadway to handle reversible lanes of traffic (bottom).

Space Weapons

—the science behind the big debate

Last year, in a move that surprised many in and out of government, President Reagan called on the scientific community to help prepare a program that would lead to a space-based weapons system, one that would shield the U.S. from a nuclear-missile attack. Since then, the concept, which was quickly dubbed a "Star Wars" defense, has been the subject of continuing debate, with noted scientists on each side.

By EDWARD EDELSON

Illustrations by Eugene Thompson

Let me share with you a vision of the future which offers hope. It is that we embark on a program to counter the awesome Soviet missile threat with measures that are defensive. Tonight, consistent with our obligations under the ABM treaty and recognizing the need for close consultation with our allies, I am directing a comprehensive and intensive effort to define a long-term research-and-development program to begin to achieve our ultimate goal of eliminating the threat posed by strategic nuclear missiles."

When President Reagan made what has become known as his "Star Wars" speech on March 23, 1983, he conjured up a vision of a world made safe from destruction by a technologically daring defense against the seemingly undefeatable.

Those who believe in that vision acknowledge that to achieve it, formidable technological challenges will have to be overcome. Whole new families of weapons must be made to fire with unprecedented speed and accuracy at elusive targets that are continents away. Now a great debate is raging about whether those challenges can be met, with respected scientists on both sides. The supporters envision this ultimate scenario:

At an unspecified time in the future, the men in the Kremlin, jittery about the growth in Western might and driven to desperation, have decided to launch an overwhelming attack. At their command, 2,000 intercontinental missiles blast off from silos across the Soviet Union and from nuclear submarines at sea.

But at the moment of attack, cruising U.S. battle stations in space spring into action. Radar and laser ranging devices pick up the missiles as they lift off. Infrared sensors zero in on the heat of their rocket exhausts. Vast computer complexes on Earth process the data from these sensors to calculate the missile trajectories within inches. The information is flashed to a fleet of American battle stations in space and on Earth.

Deadly beams of high-energy laser light, focused by high-precision mirrors, flash across thousands of miles to burn

holes in the rising rockets. X-ray lasers convert the energy of small nuclear explosions into rays that knife into the Soviet missiles, knocking them off course. Eighty-five of every 100 Soviet rockets never survive the boost phase.

The surviving missiles throw out a dazzling variety of decoys to confuse U.S. radars. Nonetheless, the tracking stations quickly sort out the real warheads from the decoys. Lasers go into action again, destroying the majority of the warheads. Projectiles launched by space-based rocket stations or flung out by electromagnetic rail guns slam into most of the other warheads. The kill rate for these mid-course interceptors is again 85 percent.

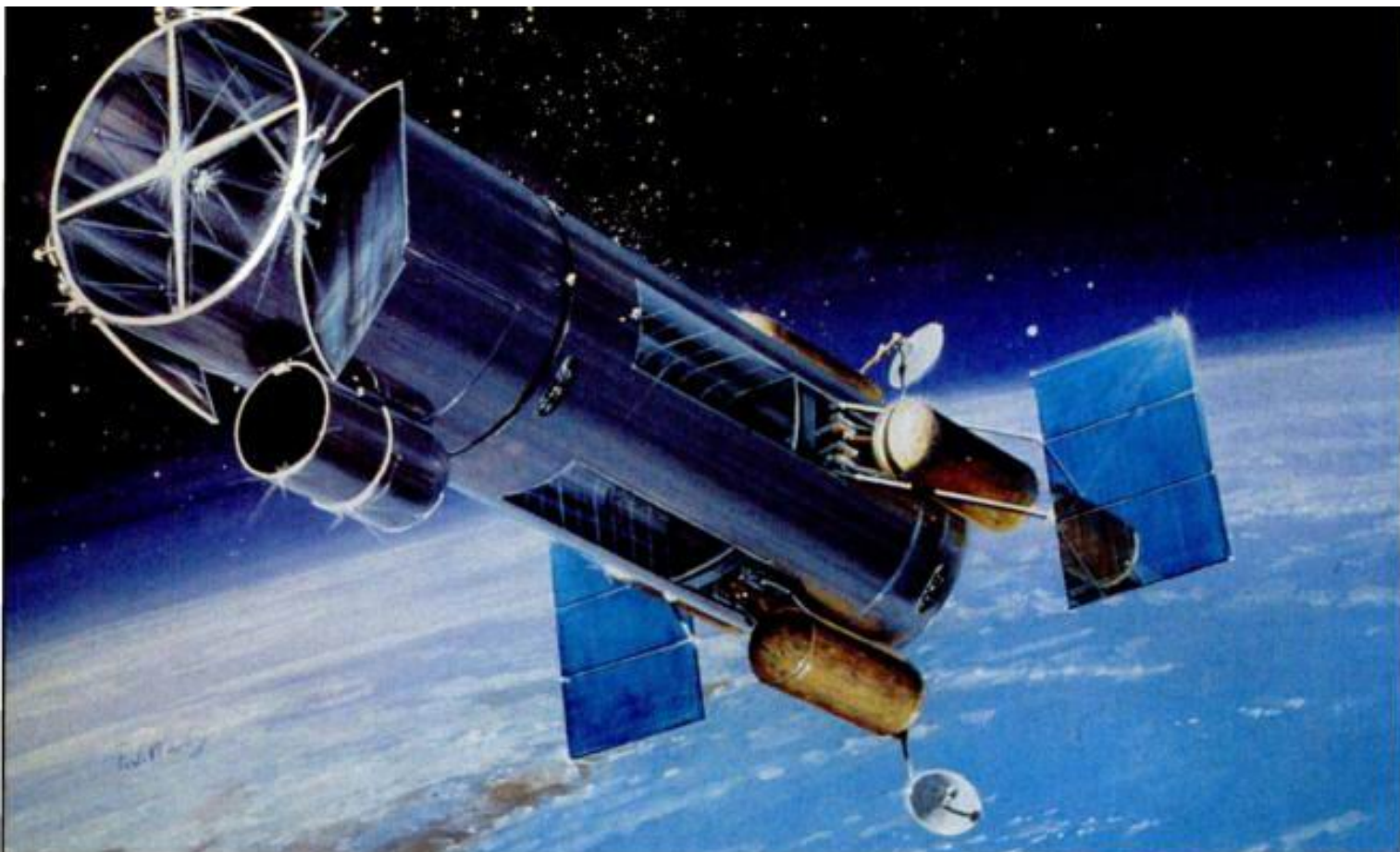
Now the small number of surviving warheads are approaching their U.S. targets. This time the task of American defensive sensors is easier. At an altitude of 40 miles, atmospheric drag sweeps the lighter decoys away. The heavier warheads are clearly identified by the sheath of plasma that forms around them. Fast-firing, high-velocity interceptor rockets meet the descending warheads with destructive force. U.S. missile silos and command headquarters are defended by concentrated electron beams that burn away the warheads. Again, 85 percent of them are destroyed. Of the thousands of Soviet warheads that were launched, fewer than 10 even come close to hitting their targets. The U.S. missile force meanwhile remains untouched in its silos and submarines, ready for the retaliation that is no longer necessary.

The real allure of that scenario is that it would not be a self-fulfilling prophecy. Given that kind of missile defense technology, supporters say, the Soviets would never dare launch a missile attack. The specter of MAD—mutual assured destruction by nuclear weapons—would fade away, and intercontinental missiles would become as obsolete as horse-mounted cavalry.

To make the scenario a reality, the Department of Defense is proposing a program to develop five broad capabilities:

- A surveillance, tracking, and acquisition system that would keep tabs on enemy missiles during peacetime, detect and follow them during launch, and use an intricately coordinated combination of radar, lasers, and infrared sensors to guide our missile-destroying weapons.

Continued



Short-wavelength beams spread less as they travel, Tanimoto says. "And shorter wavelengths couple better to metal targets," he adds.

Among the candidates are the hydrogen fluoride laser, which produces a beam at a wavelength of 2.7 microns (0.001 in.) when energy is pumped into a cavity containing the two gases. A more exotic concept is the excimer laser [PS, May '83]. An electron bombardment is used to ionize a noble gas such as xenon, which reacts with fluorine to form a gas that can be made to emit intense laser beams. The shorter wavelengths of the excimer laser are attractive, Tanimoto says. "However, chemical lasers are further developed than excimers," he notes. "They also tend to be more efficient in terms of energy conversion."

One new development in laser-weapon technology is the use of something called the hydrogen Raman cell to improve beam quality. The Raman cell is simple in principle—as simple as a tube with windows at each end, says James Swingle of Lawrence Livermore Laboratory. Light from one or more excimer lasers is beamed into the cell, where it interacts with the hydrogen to produce a beam of slightly longer wavelength.

"Using the Raman cell, you can shift the excimer laser light into a wavelength that is more readily transmitted through the atmosphere," Swingle says. "You can also combine a number of excimer beams in one cell and get a clean beam coming out. The beam from an excimer laser tends to have distortions in it, and the Raman cell cleans it up."

There's a trade-off, though. To hit missiles in the boost phase, laser beams will have to be directed by mirrors in space. As you go to shorter wavelengths, you need ever more perfect mirrors.

"This is a problem that *has* to be solved if we consider space-based systems," says Swingle. "We must control the configuration of an optical system to a fraction of a wavelength over apertures of 15 meters [49 ft.]. The system must come up rapidly, be completely stabilized, and focus its output over distances of thousands of meters."

It probably won't be possible to build one-piece mirrors that will do the job, Swingle warns. Instead, the missile-

A chemical laser weapon is the goal of the Alpha Project, one part of the Department of Defense's Triad Program. The artist's concept from TRW shows a spaceborne hydrogen fluoride chemical-laser battle station capable of propagating a laser beam that remains focused as it lances through space. A second leg of Triad, the Talon Gold pointing and tracking telescope (for target acquisition and engagement), is mounted forward. The tanks on the lower section hold cryogenic helium. The tanks are stored internally during launch and swung out in space. According to TRW, the developers of the Alpha project, the laser shown here could blast missiles with a five-megawatt beam.

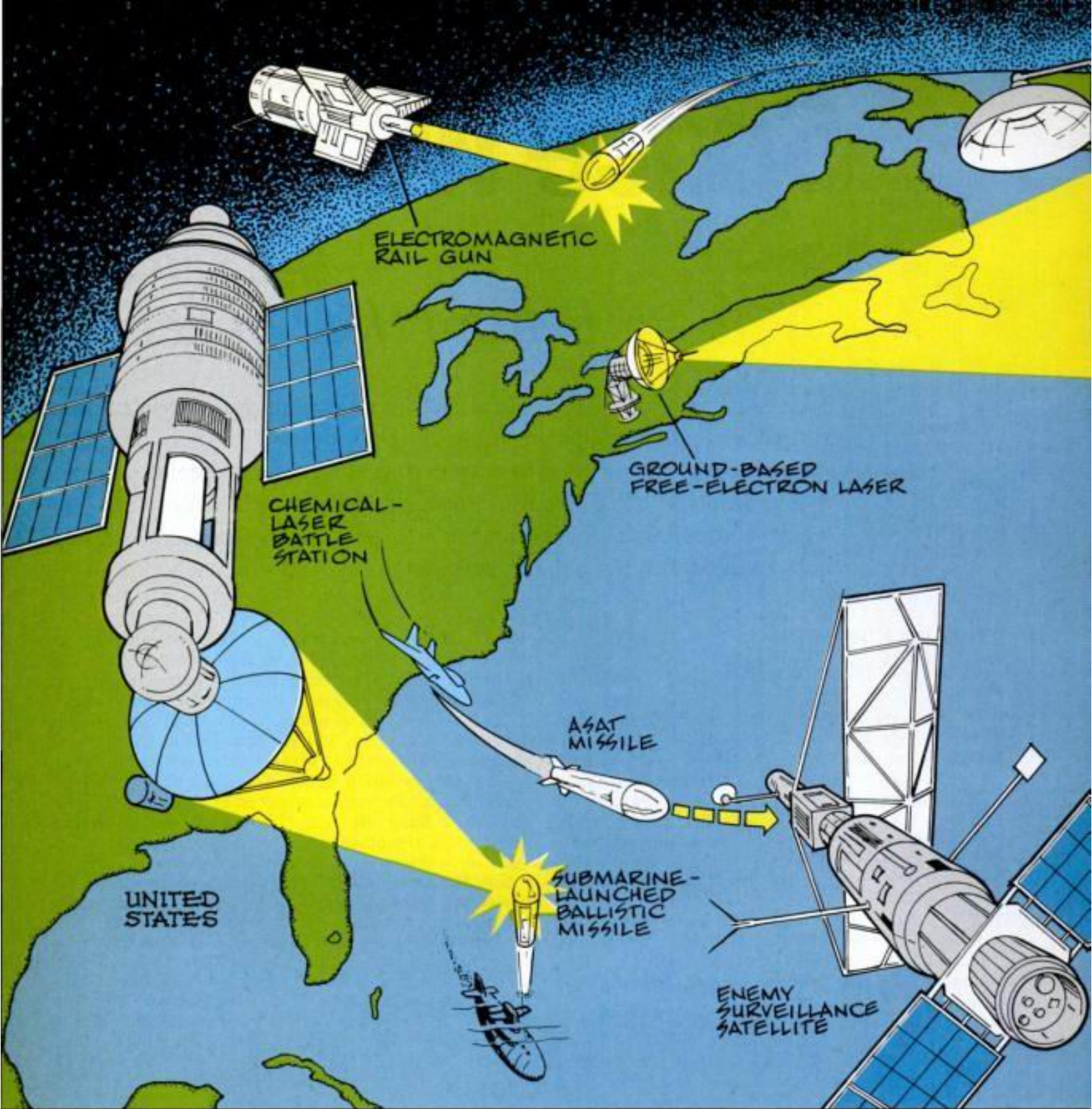
defense system would borrow an idea from astronomers, who are building telescopes made of multiple mirrors that are coordinated by computers to form, in effect, one large mirror [PS, Oct. '81]. "It's certainly a heroic effort, but it's one that has to be solved if these technologies are ever to make sense," he says.

It's even more complicated when the laser system is put into space along with the mirror, Swingle adds, because "if you have a big chemical laser humming away, one wonders if you can get the optical platform stable enough."

One solution would be to keep the laser on the ground and transmit its beam up to a space mirror. The problem here is atmospheric distortion of the laser beam. But that is solvable, says George A. Keyworth II, the President's science advisor. The method is called adaptive optics. A small laser in space sends a beam toward the ground. A battery of ground-based lasers detects the laser light and instantly alters its output to compensate for the distortion caused by the atmosphere, maintaining the coherence that gives the laser beams their deadly power. "We have learned how to propagate a beam through the atmosphere and account for its distortion," Keyworth says.

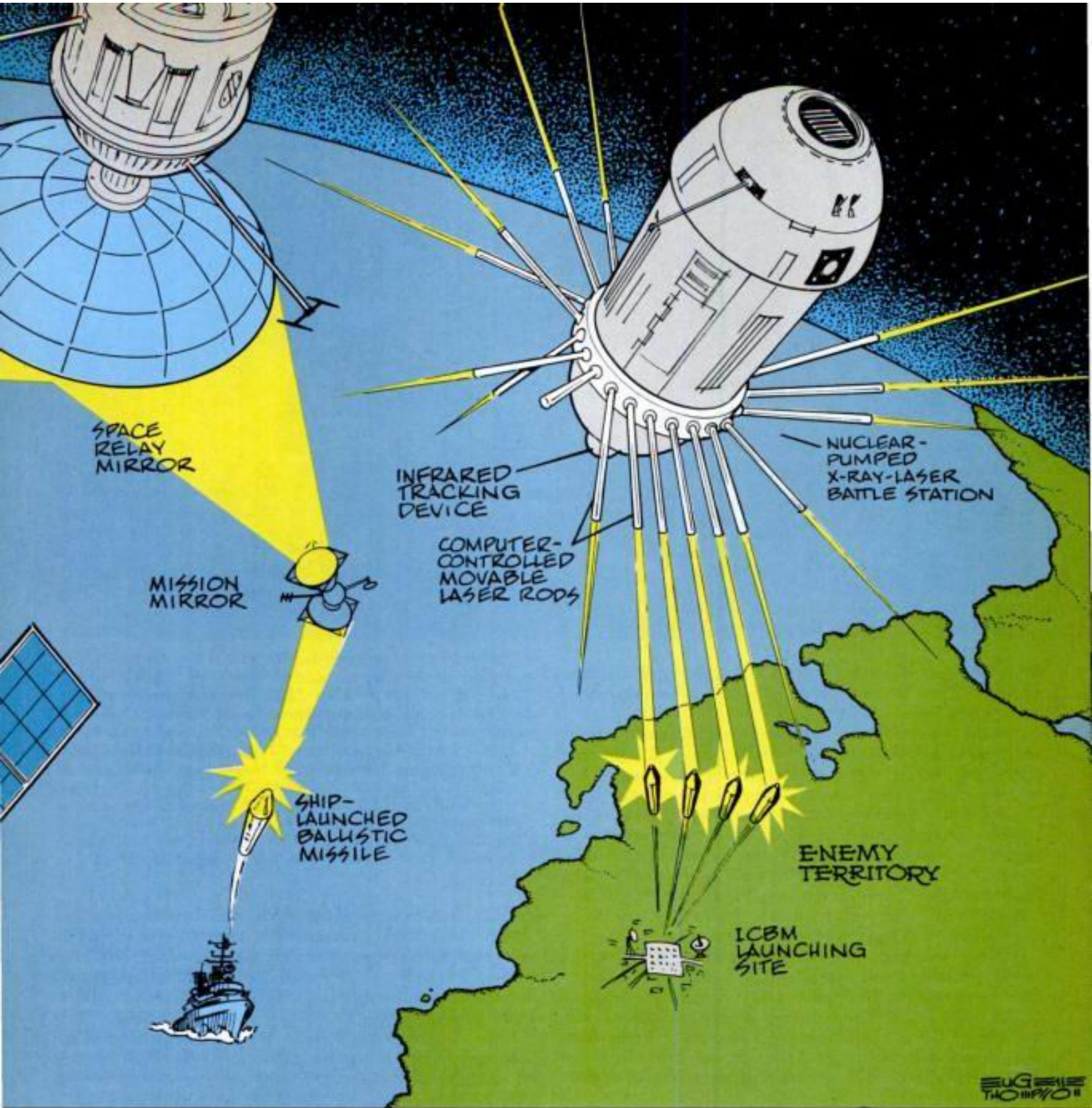
An entirely different solution is to use X-ray lasers, whose wavelengths are so short that they can't be directed by mirrors. Although nobody talks much about it, it's generally agreed that the people at Lawrence Livermore Laboratory have successfully conducted an underground test of an X-ray laser. It had to be underground because the

Continued



A multi-tiered space defense calls for a variety of weapons to neutralize missiles in any stage of flight. Among the weapons being investigated are nuclear-pumped X-ray lasers, which may be clustered so that a single nuclear detonation can saturate an area with X-rays; electromagnetic rail guns, which fire hypervelocity projectiles; chemical lasers, envisioned both as ground-based and space-based battle stations (in space there is no atmosphere to diffuse the beam); and free-electron lasers, which are capable of propagating a tunable laser beam of short wavelength. Mirrors, which are needed to focus and relay the laser beams, must be stable, near-perfect optically, and able to withstand enormous laser energies. Anti-satellite weapons, one of the few technologies available now and one the U.S.S.R. probably possesses, will also play a part in space defense.

- An arsenal of directed-energy weapons. Most would be lasers, based in space and on the ground. Some would use gases such as hydrogen fluoride to emit missile-killing beams of light. Others would use excimers—molecules that are “excited” into higher energy states by bombardment with electrons—or a gas of free electrons floating through magnetic fields to generate their laser beams. Still others would emit deadly jolts of X-rays with energy derived from nuclear explosions. Giant mirrors on Earth or in orbit would aim the laser beams with precision. Particle-beam weapons—giant military mutants of the cathode-ray tube—would fire blasts of protons, ions, or electrons at incoming missiles.
- A family of kinetic-energy weapons, including interceptor missiles and hypervelocity guns that would boost projectiles to supersonic speeds by electromagnetic forces.
- A vast computerized battle-management system to coordinate every element of the defense.



• An ongoing research-and-development program to keep the system's technology up to date.

The Defense Department has been working on some elements of the system for years. Its Project Alpha, run by TRW, Inc., is developing powerful chemical lasers. Talon Gold, whose prime contractor is Lockheed Missiles and Space Co., is developing control systems. Lockheed is also prime contractor for LODE—the large optical demonstration experiment—designed to produce the prototype of the exquisitely accurate mirrors needed by chemical laser weapons. Itek Corp. is building the mirror, which is scheduled for completion in 1987.

The present controversy centers on whether these systems can be built at all, and if so, on the feasibility of putting them together into a working missile defense.

The technological challenges aren't being underestimated even within the administration. When Richard D. DeLauer, the Defense Department's R&D man, appeared before a

Congressional committee last year, he showed a slide containing eight blocks of "key technology candidates"—space-based infrared sensors, directed-energy weapons, and so on. "Every single one of those blocks that I have on the Viewgraph is equivalent to or greater than the Manhattan Project," DeLauer said.

But the Defense Department hasn't been standing still, DeLauer added. It has already spent \$2 billion on directed-energy weapons alone, producing some of the building blocks of a ballistic-missile defense system.

Work is proceeding on a whole family of lasers that emit intensely powerful beams of light. In laser weaponry, shorter wavelengths are the best, even though they are more readily absorbed by the atmosphere, explains Douglas Tanimoto, former head of the directed-energy-weapon program at the Defense Advanced Research Projects Agency, who is now at Maxwell Laboratories in California.

Continued

*Around the world
without refueling?*
**Rutan's
ultimate flyer**

Aviation's last milestone, says Burt Rutan, one of our most innovative aircraft designers, is an around-the-world, nonstop, non-refueled flight. He plans to reach that goal with Voyager, an all-composite plane with a wingspan of 111 feet that is designed to carry two crew members 25,000 miles.

By BEN KOCIVAR

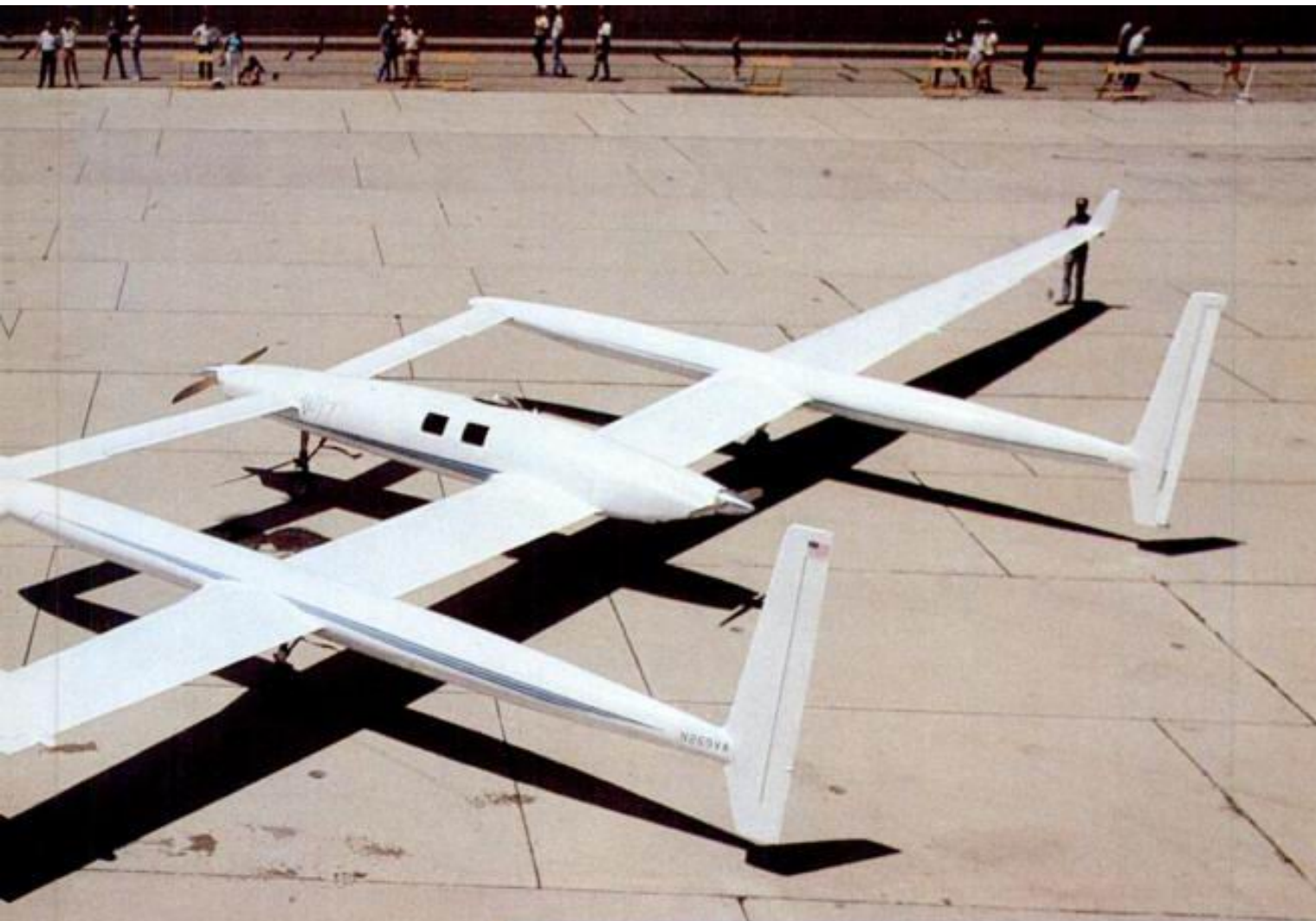
MOJAVE, CALIF.

Winds gusting to 40 knots were blowing unhindered through the Mojave Airport. A handpicked crowd of aviation enthusiasts were squinting in the sun as dust swirled, trying to keep their eyes fixed on the doors of the hangar where Burt Rutan's latest aircraft, Voyager, sat hidden.

Would Voyager appear? A member of its construction team raised my apprehension level when he told me: "Burt spent three years designing and building this lightweight to just about float around the world. He's not going to let it get tossed over during a roll-out ceremony. You may be snapping your photos inside the hangar."

But the winds abated, the hangar doors peeled open, and

Continued



Voyager's 111-ft. wingspan seemed endless to the crowd at roll-out. By contrast, two-ft.-wide cockpit (above) and two-by-7½-ft. cabin, shown in full-scale wooden model (right), are all too finite. Dick Rutan and Jeana Yeager (above right) will sleep in turns to combat fatigue and jet lag. Forward canard, fuselage, and huge main-wing outriggers will store fuel. Transparent pilot bubble, used during takeoff and landing, is visible atop fuselage.



Invisible bomber

—secrets of the plane that radar can't see

Airmen call them "stealth" planes. To enemy radar, they can look like hummingbirds

By JIM SCHEFTER

ILLUSTRATION BY DEAN ELLIS

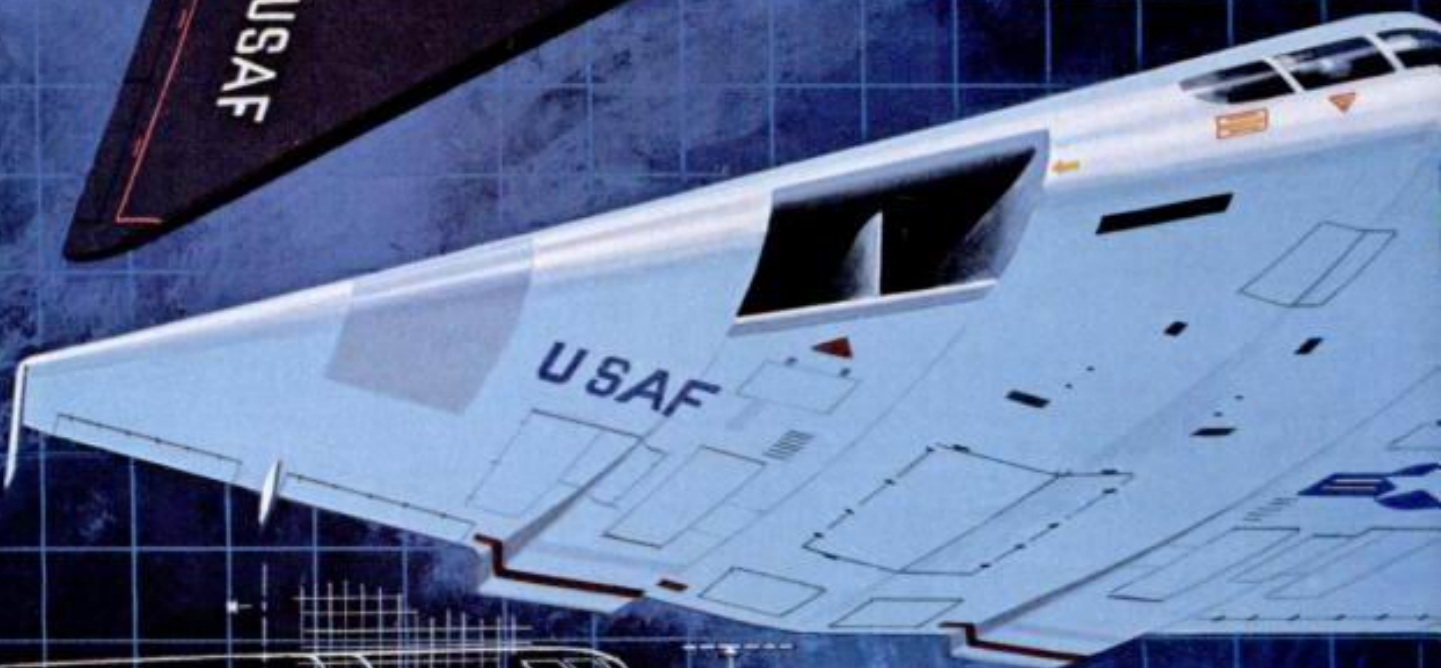
Shaped like a broad, flat wing with only a smoothly blended windscreen revealing its cockpit, the bomber skimmed across barren polar terrain at nearly 600 mph. Barely 400 feet below, ice floes vibrated to the roar of its concealed jet engines. The early-warning radar fence lay behind, its operators unaware that the first line of defense had already been penetrated.

More radar waited ahead. Hugging the terrain to take full advantage of hills and valleys, the flying wing crossed

Continued



Twin-engine, delta-wing bomber concept developed by Rockwell International (below) would have smooth underbelly, except for stabilizing fins (detail, bottom). Stealth plane is designed for heavy payload, despite its small size. Another design from Boeing (left) has delta wing and a V-tail for low-level, long-range missions.





SR-71 Blackbird spy plane (left) is one of the earliest designs with anti-radar stealth concepts. A blue-black coating is thought to have radar-absorbing properties. The engines blend smoothly with the wings, and slanted tail fins minimize radar reflections. British Vulcan bomber (above) also has stealth features: Engines are concealed within its triangular wing, unlike engines on B-52s, which capture and reflect radar signals.



Aerodynamic efficiency is boosted in another Boeing design that trades off some radar and infrared invisibility for better engine performance. Design stresses long-range capability.

Angled engine inlets (detail) are shrouded to cut radar reflections in this Boeing concept. Engine outlets are designed to reduce heat visibility from below.

Popular Science®

The What's New magazine

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Double-shell houses

At last—we know why they work

Special section:
THE '83 IMPORTS

INVISIBLE BOMBER

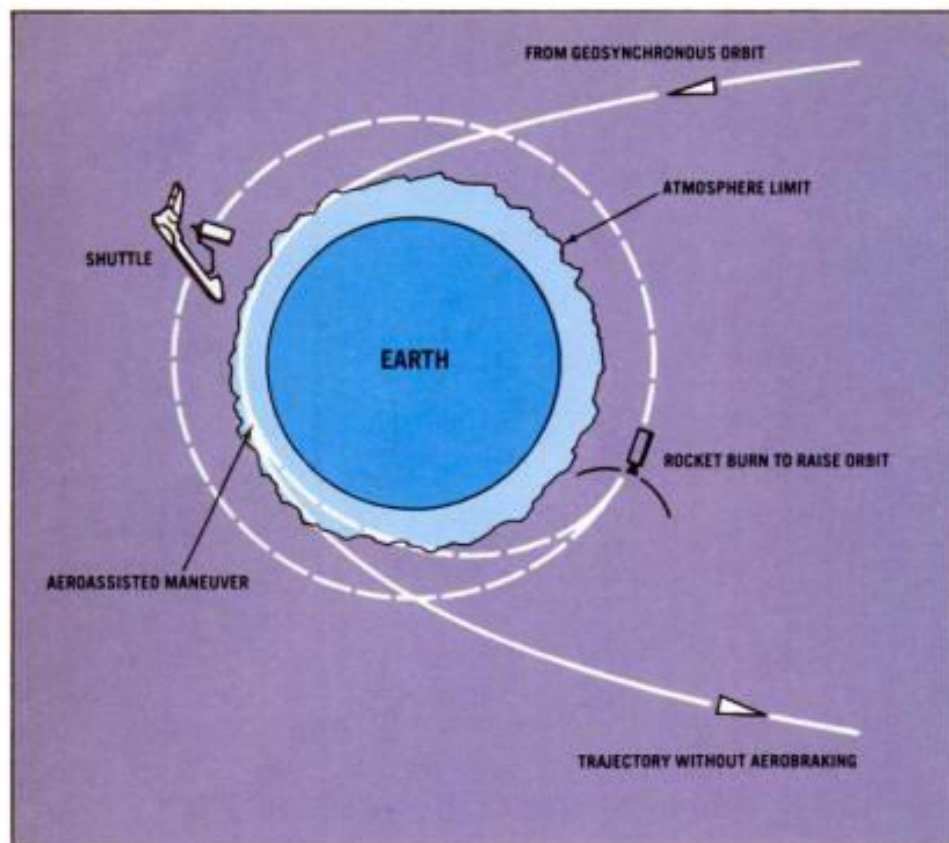
—secrets of the plane that radar can't see

Computer programs to
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726597





Aerobraking of rocket released from shuttle and put into higher orbit requires com-

plex maneuvers to graze atmosphere, reducing velocity for return to the shuttle.

On a chilly winter day in July, Sandeman escorted me down three flights of stairs to his basement machine shop and physics laboratory. The tall Australian stood beside what looked like a mammoth cannon, a 30-foot-long stainless-steel pipe two feet in diameter. Another pipe, 20 feet long and three inches in diameter, was fixed to one end of the larger tube. The pipes serve as a shock tunnel to simulate vehicle entry into the atmospheres of various celestial bodies.

"To get a shock wave in the laboratory, you do something like bursting a balloon," Sandeman said. He handed me one of the "balloons," a steel plate six inches square and nearly $\frac{1}{4}$ inch thick. Six jagged holes, seemingly ripped by elephant-gun slugs, punctured the plate.

During tests, I learned, a piston compresses helium gas in the larger pipe. The pressurized helium ruptures a metal plate inserted between the two tubes. Inside the narrow tube on the other side of the metal membrane are gases—say, nitrogen, argon, and methane for Titan, or air for Earth.

"You get a wave traveling out in a three-dimensional way—more like a blast wave. The tube simply focuses that shock wave," Sandeman said. "The piston can push the pressure up to 800 atmospheres and around 6,000 degrees Kelvin [10,340 degrees F], so you get very fast shock waves, which, in turn, can heat the mixture for the wind-

tunnel nozzle to around 12,000 K."

Brass or steel models of blunt-nose spacecraft, about the size of paper staplers, are inserted inside the shock-tube nozzle. A high-speed Hasselblad camera records the shock waves surrounding the spacecraft models, or tiny sensors attached to the models register heat and pressure.

"If we can give NASA engineers data on the heat-transfer conditions, they can put the data into their computers and work out what's going to happen to the insulating surface on a vehicle," Sandeman said. He ran his finger over the colored shock waves on a photographic print. "For about one millisecond," he said, "the shock tunnel produces a stream of gas moving at close to Mach 20—about 12 kilometers per second [27,000 mph]—which is the speed of a spacecraft coming into Titan for aerocapture."

Supertankers in space

Engineers are applying such data and aeroassist concepts to planned space-shuttle missions above Earth, as well as to sorties to distant planets. Cruz, who has devoted most of his seven years at JPL to aeroassist, explained: "The space shuttle is like a supertanker carrying only a couple of barrels of oil. It takes a tremendous amount of fuel and power to get that tanker away from the loading dock—that is, Earth and its gravitational field.

"But when we get into space and

away from gravity, we need only the small engine of a pickup truck to actually deliver those barrels of oil—a mission's scientific package—to a higher orbit or to other planets," Cruz said.

He envisions a typical aerocapture-mission scene like this: A scientific package, or perhaps a communications satellite destined for a high geosynchronous Earth orbit, is attached to an Orbit Transfer Vehicle (OTV). The OTV has a drooping, blunt-nose design to provide lift capability for maneuvers. An OTV "pickup truck" is loaded into a shuttle and launched from Florida. Once in a 200-mile Earth orbit, the shuttle opens its cargo doors and releases the OTV, which rockets into geosynchronous orbit—about 22,000 miles out—over the equator.

Now the OTV and payload separate. While the delivered goods remain in orbit, the OTV burns its rocket to head back to Earth. "The OTV makes maneuvering corrections to hit Earth's atmosphere at about 140 miles up," Cruz said, "and on a flight path to ultimately rendezvous with the shuttle." Once the OTV hits the atmosphere, the new design comes into play: Two small flaps on the rear of the craft are positioned to maximize the surface drag of the craft in the atmosphere automatically.

"The flaps steer the OTV through aircraft-like banks and turns, but no fuel burn is necessary," Cruz explained. "These are completely unpowered maneuvers. Essentially, you dissipate the velocity energy with the banks and turns. The on-board computer will be programmed to tell the craft what's going on, estimating parameters needed to get into the shuttle's orbit." When the OTV bottoms out in the atmosphere beneath the mother shuttle, a flap correction will angle the smaller vehicle upward again for rendezvous.

After hookup with the shuttle, the OTV can be refitted for another run to high orbit or be packed in the cargo bay for return to terra firma. Atmospheric entry will generate heat, of course, so the aerocapture vehicle will have a reusable heat shield. "We're looking at something called Flex—flexible, reusable composite insulation," Cruz said. "It's similar to the shuttle tiles but not as brittle."

Spacecraft equipped with aerobraking devices will be launched in the same manner as aerocapture vehicles. The multi-pass technique of aerobraking allows the craft to tiptoe into the orbit needed to carry out its mission. Aerobraking vehicles are especially appealing for interplanetary missions, given the unknowns of a foreign atmosphere, the complexity of navigation, and the time needed for signal trans-

Silver bagel and flying carrot

—NASA's new shapes for space

Next-generation spacecraft will use aerodynamic drag to double their payloads

By J. T. JOHNSON

PAINTING BY DEAN ELLIS

PASADENA, CALIF.

A curious-looking spacecraft, unlike anything I've seen before, was assembled as a five-foot-long model at the Jet Propulsion Laboratory here in Pasadena. The space-probe design isn't semi-spherical with insect-like legs, like vehicles now dotting the lunar, Venusian, and Martian surfaces. Nor does the model have an airplane-ish appearance like the space-shuttle vehicles.

Instead, one of JPL's latest creations for outer space has a drooping, blunt nose—somewhat like a Concorde jet's front end—engineered to slam into the mysterious atmosphere surrounding Saturn's moon Titan. Other probes dreamed up by JPL and NASA are more bizarre. Some even look like giant silver bagels or badminton shuttlecocks.

What's happened to the sleek, javelin-like spacecraft of science-fiction films? After talking with U.S. aerospace experts and visiting a lab in Australia that's creating exotic planetary atmospheres for research, the logic behind these strange new shapes became clear to me: Sleek, sporty spacecraft may look great on showroom floors, but they can't carry big payloads and still get good mileage.

Space engineers are following Detroit's economy push. With space missions dwindling and budgets tight, project managers want to boost space-

vehicle efficiency by using the forces of nature. The goal: to use planetary or lunar atmospheres to steer and slow spacecraft by means of "aeroassist" designs. Instead of depending entirely on fuel-hungry rockets for maneuvering, an aeroassist-design spacecraft will carry twice the payload and consume less fuel.

"It costs about \$35,000 to put a kilo [2.2 pounds] of payload into space using a propulsion system now," said JPL task supervisor Manuel Cruz. "Using aeroassist, it would cost about a sixth of that—\$6,000." An additional benefit, he says, is that reducing engine capacity and fuel consumption enhances spacecraft reusability: You don't have an expended rocket system to throw away when the spacecraft returns from a mission.

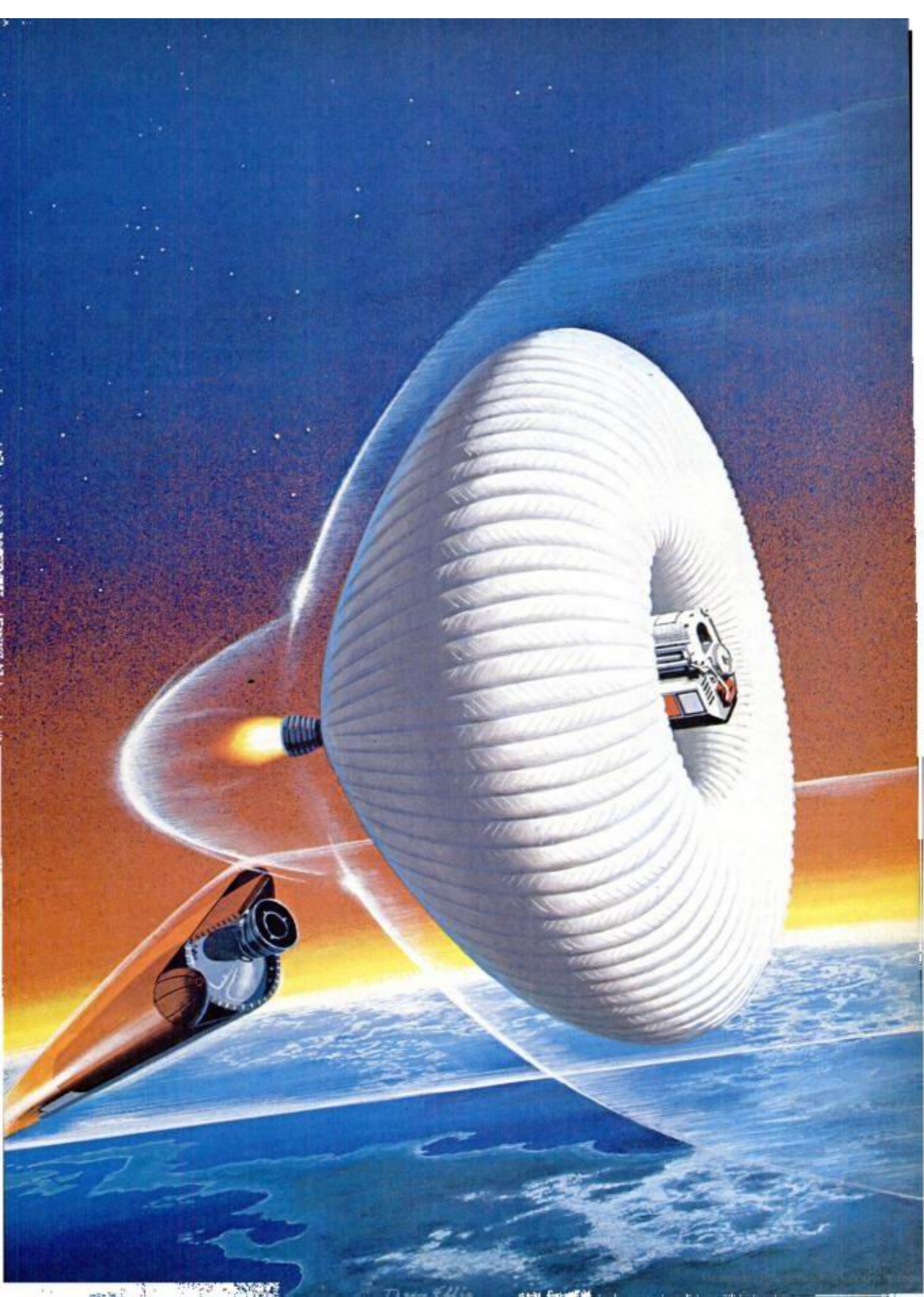
Aeroassist spacecraft may evolve into two types: those designed for "aerocapture" and those intended for "aerobraking." Aerocapture involves a single pass at astonishing speeds, deep in a planet's atmosphere. A smooth aerodynamic shape is a must. Aerobraking, though, requires many high-altitude passes through an extremely thin atmosphere. Aerobraking craft will deploy large umbrella-like structures or inflatable balloons for drag.

What happens to a spacecraft when it slams into a planetary atmosphere at 24,000 mph? At the Australian National University in Canberra, Dr. John Sandeman and his colleagues are simulating such collisions for NASA. Engineers must have this lab data before computers can design an aeroassist craft and its control system.

Continued

Aeroassist vehicles planned for planetary missions and orbital shuttles in the 1990s will use atmospheric braking to reduce fuel requirements. One proposed orbital craft (right, bottom) has inflatable wings; above it, an inflatable-balloon design.





PS HOME OF THE YEAR 2000

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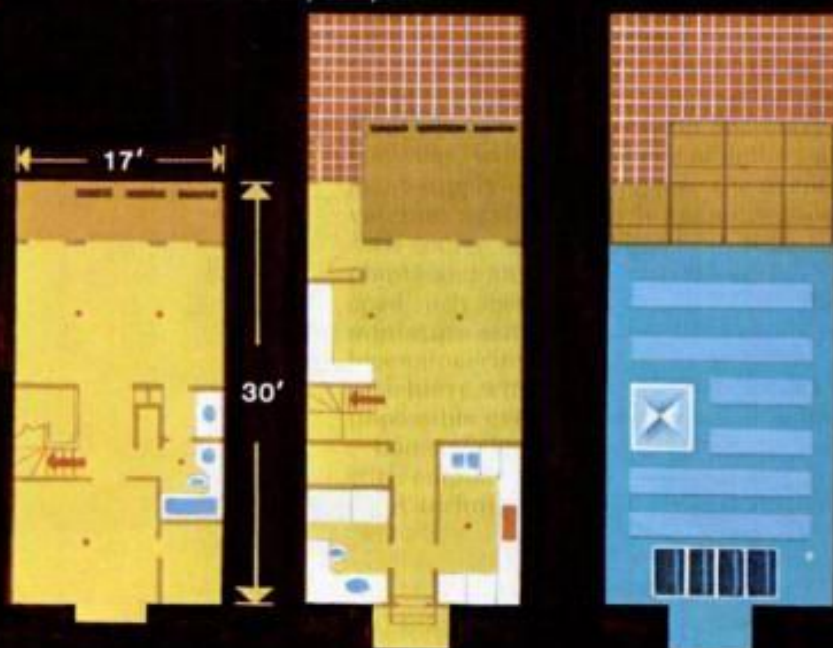
These are some of the attributes experts see for the typical American home of the year 2000. The traditional American house-and-yard has already become too expensive for most young house buyers, with a consequent shift to smaller, clustered dwellings (developers call them "town houses") and cooperative or condominium ownership. At the same time, smaller families, frequently childless, require fewer rooms—which are becoming increasingly multi-functional. The living-dining-family-room-den, already here, could become the standard in 2000. The clustered house, heavily insulated, and by its nature energy conserving, will draw its heat largely from the sun with backup heating depending on region: radiant electric panels in some cases, auxiliary stoves, perhaps, in others. Computerized electronic devices will receive mail, protect the house, and monitor its functioning. As water gets more expensive, gray-water recycling systems will become more common; certainly, low-flush toilets and miserly shower heads will become standard. More houses will nestle into the earth, or go totally underground, to take advantage of

Mother Earth's even temperature. Houses will be adapted to climate and region—no longer the same ranch house in California and Minnesota. Building materials? Perhaps a new structural insulating material. More wood, suggests Dennis J. Hardman of APA (American Plywood Assn.): It's renewable; it's versatile; it uses comparatively little energy to produce. Construction systems will be modularized, predicts John R. Hagely of the Battelle Columbus Labs: Heating, cooling, plumbing, and electrical systems will be plugged together. Toward modularization, a core inventory of 15 or 20 panel configurations would offer a builder almost unlimited flexibility, APA suggests. Insulating materials of tomorrow? Infinite possibilities. The same with glazing materials: foamed, insulating glass; electrochromic glass that would act as a chemical shutter, blocking light and radiant heat as desired; unbreakable, non-deteriorating plastics. Certainly, low-emissivity glazings will be common.

Passive heating and cooling systems will be standard, with heat-storage systems that—most likely—use phase-change materials (liquefying when heated) for maximum efficiency. And in the tight house of tomorrow air-to-air heat exchangers will both ventilate and provide make-up air.—*Everett H. Ortner*



PS cluster house, part of town-house group, is set into earth, with entrances at two levels. It is passively heated and cooled. Its sunspace (solar greenhouse) glazing is a chemical-shutter system that bars or admits sun based on temperature. Thermostats control intake louvers and fans and direct flow of air. In winter, with daytime sun, heated air in the sunspace flows up and into the house. When the house is warm, the air is redirected around the living quarters, through a panel-duct system, to heat-storing cylinders containing phase-change materials in an under-floor wood-foundation plenum. At the same time, phase-change materials in sun-facing wall also store heat, releasing it when the sun is down. At night, circulation is internal, with plenum bank giving up heat. In summer, earth-cooled plenum cools house. (For extra cooling, a community ACES system might use a giant winter-frozen ice block.) Kitchen has induction cook top, computer-controlled microwave oven, below-counter refrigerator and freezer, home-monitor/computer screen, electroluminescent lighted walls above counters. Den area has wall-filling flat TV screen, central electronic home-monitoring controls and screen, and voice-command family computer.



Simple two-bedroom house has kitchen, half bath, multi-use living-dining-room-den on lower floor, with entrance from patio or via steps from upper-level street. House has

built-in sprinkler and smoke-detection systems. Total space: 1,020 sq. ft. Solar collector for hot water and photovoltaic cells cover roof.



Modular paneling for interior surfaces contains plumbing and electrical hookups, plus ducting for air circulation. Plumbing and ducts are plastic.



PS CAR OF THE YEAR 2000

We know what the car you'll drive in the year 2000 will be like. We know because PS editors recently interviewed research engineers at major auto makers and studied prototypes from the U.S., Europe, and Japan. The car that resulted is not science fiction: By examining the directions of today's research, we think it's possible to predict how automobiles will evolve by the beginning of the 21st

century. With a body based on Ford's Probe III prototype, the PS 2000 incorporates features that will enable the average car of 2000 to double the fuel efficiency of today's cars. Of course, we are not implying that there will be one car. You'll see small cars for commuting; family sedans for long trips; station wagons for extra load capacity; and even high-performance sports cars. —Richard Stepler

FUTURE ENGINES, DRIVE TRAINS

In 2000, according to an American Society of Mechanical Engineers report, we may drive cars with hydrogen-powered internal-combustion engines, flywheel or compressed-air energy-storage modules, all-electric or electric hybrid engines, as well as conventional petroleum-fueled engines. GM thinks new fuels are out of the picture for now. It will use port-fuel-injection gasoline engines and direct-injection diesels. A Renault official suggests a direct-injection diesel of four or fewer cylinders. VW's Auto 2000, previewed in PS, July '80, and now in prototype, has a one-liter, three-cylinder supercharged 45-hp diesel that delivers 71 mpg at a constant 55 mph. This car also has a flywheel for automatic engine restarting in stop-and-go traffic. Continuously variable automatic transmissions will be more efficient than manuals, says GM, and may eventually be universal.

FUTURE SHAPES, MATERIALS

According to VW, which has pioneered in aerodynamics since 1966, decreasing drag is more significant in improving mpg than reducing a car's weight or tires' rolling resistance. Future sleeker cars will have flush window glass, higher rear decks, faired-in bumpers, hidden windshield wipers, flatter wheel covers, and fully enclosed underbodies (for more details, see "Low-Drag Cars," PS, Sept. '81). PS 2000's drag coefficient is 0.22, half of today's average of 0.44. That improves mpg by 27 percent. According to GM, the average car's weight in 2000 will be one-third that of today's. Glass will be a thinner, lighter glass-plastic sandwich; bumpers, fenders, and grilles will be plastic to save weight and resist damage and corrosion. Higher-pressure radial tires, made of thinner tread stock, will have half the rolling resistance of today's best, says Renault.





THINNER, LIGHTER GLASS-PLASTIC SANDWICH

CONTOURED SEATS, AUTOMATICALLY ADJUSTABLE

LOW-ROLLING-RESISTANCE
TIRES

THE INTELLIGENT AUTOMOBILE

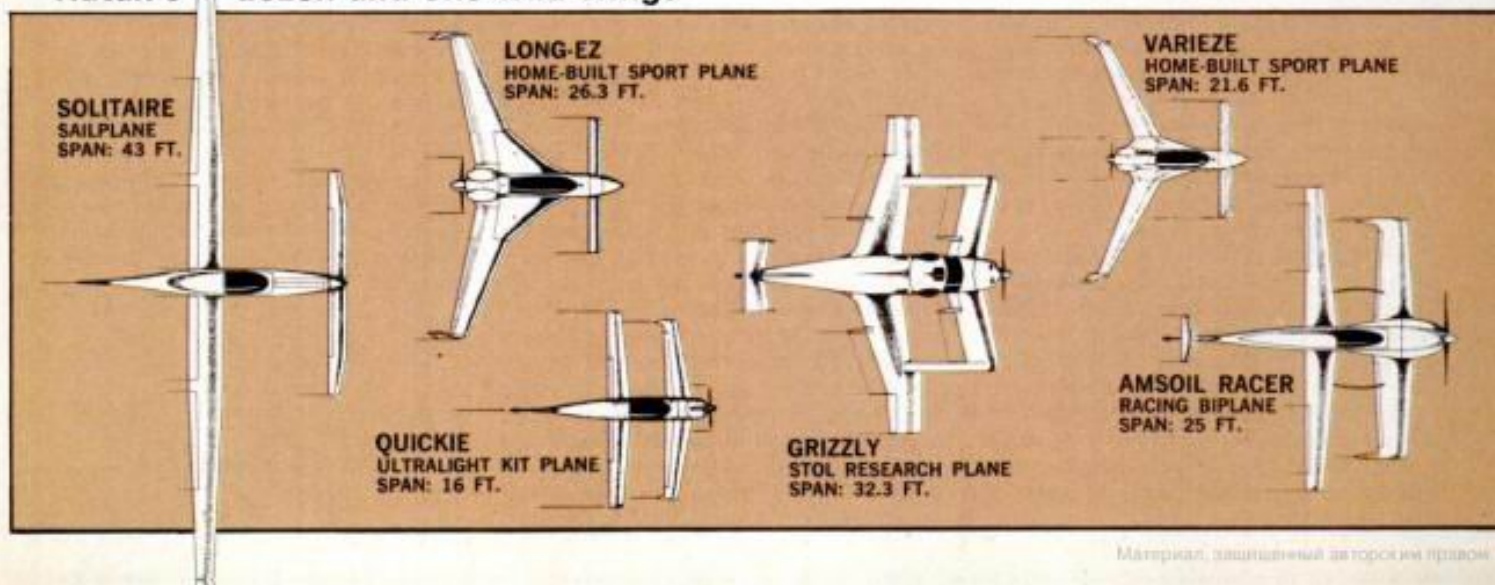
PS first previewed the coming electronics revolution in automobiles in our August '79 cover story. Many of the features we outlined are in Toyota's experimental EX-11: microprocessor-controlled engine and transmission to improve mileage and performance; radar to track vehicles in front; variable-power steering that's light at low speed, heavier at higher speeds; electronic height control to improve aerodynamics and stability; four-wheel skid-control system; and sonar to warn of cars to the rear. The dash has a color-TV monitor for displays of air conditioning, audio, cruise control, speed, navigation, plus TV broadcasts. Sound like too many buttons to push and still keep your eyes on the road? The EX-11 responds to verbal commands and replies via a speech synthesizer.



Aeronautical wizard Burt Rutan and his fleet of **fantastic flyers**



Rutan's dozen-and-one wild wings



The king of the home-built canard widens his horizons

By **BEN KOCIVAR**
PHOTOS BY PAT STORCH

Some people spend their lives dreaming the impossible dream. Burt Rutan dreams strange-looking airplanes. Then he builds and flies them.

Rutan, 38, is the aeronautical maverick behind some of the oddball aircraft featured in *POPULAR SCIENCE* in past years. I first became a believer after a wild, swooping ride in his virtually stall-proof canard, the VariEze [PS, Nov. '78]. Four years earlier, though I didn't know then who Rutan was, I'd "flown" another of his amazing creations: a spring-balanced metal frame that linked an engineless BD-5 airplane to a pickup truck for safe, realistic training runs [PS, Aug. '74]. Just last August, I reported on another company's two-seat redesign of his single-seat Quickie.

All of those projects grew out of Rutan's first love: designing low-cost airplanes for do-it-yourself plane builders. He now sells complete plans for five such designs, with another—a self-launching sailplane—on the way. But his interests and accomplishments go far beyond the fledgling home-built market.

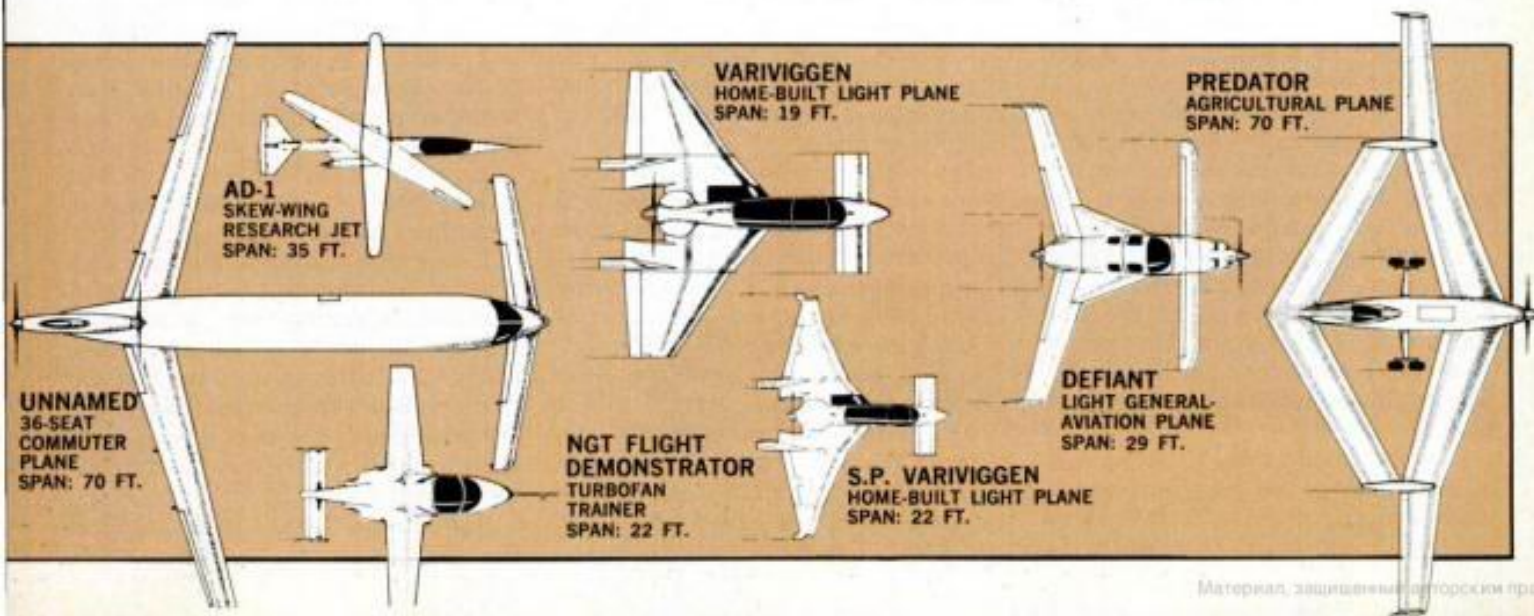
Pictured on the cover of this issue is his latest flying machine, the Grizzly—the prototype for a short-takeoff-and-landing canard that Rutan considers too big and complex for home-builders. Other recent designs off his drawing board similarly indicate a broadening of his interests toward larger craft. He has also built and tested research planes for NASA and a major military-plane builder. He is even considering going into produc-

Continued



Squadron of canards surrounds Rutan's new Grizzly (above). A research plane to test applicability of canards to STOL operation, Grizzly's designed for back-country trips: The four-seater's rear seats fold for sleeping, and it will get amphibious floats. Canopy has bulging side windows for straight-down vision. Huge flaps on canard and forward-swept main wing add 45 sq. ft. of wing area. Rigid connections

between wings provide torsional bracing, hold fuel. Structure is fiberglass and carbon-fiber facings over rigid foam. Top: Rutan with two-thirds-scale Next Generation Trainer, built by Ames Industrial. Fairchild Republic designed craft's shape; Rutan, its structure. Then Rutan's brother, Dick, and Mike Melvill conducted flight tests. Facing page: Rutan's VariViggen (right) and Long-EZ.



The design war behind the Army's **SUPERCHOPPERS**

● The Army is working to design a new helicopter that will fly faster, be more maneuverable, carry more-effective weapons, operate more reliably, and require service less frequently. It will make use of many advanced technologies and may not even look like present-day helicopters. In fact, it will be so different that it will have to be designed and built in an entirely new way—with the cockpit receiving first priority.

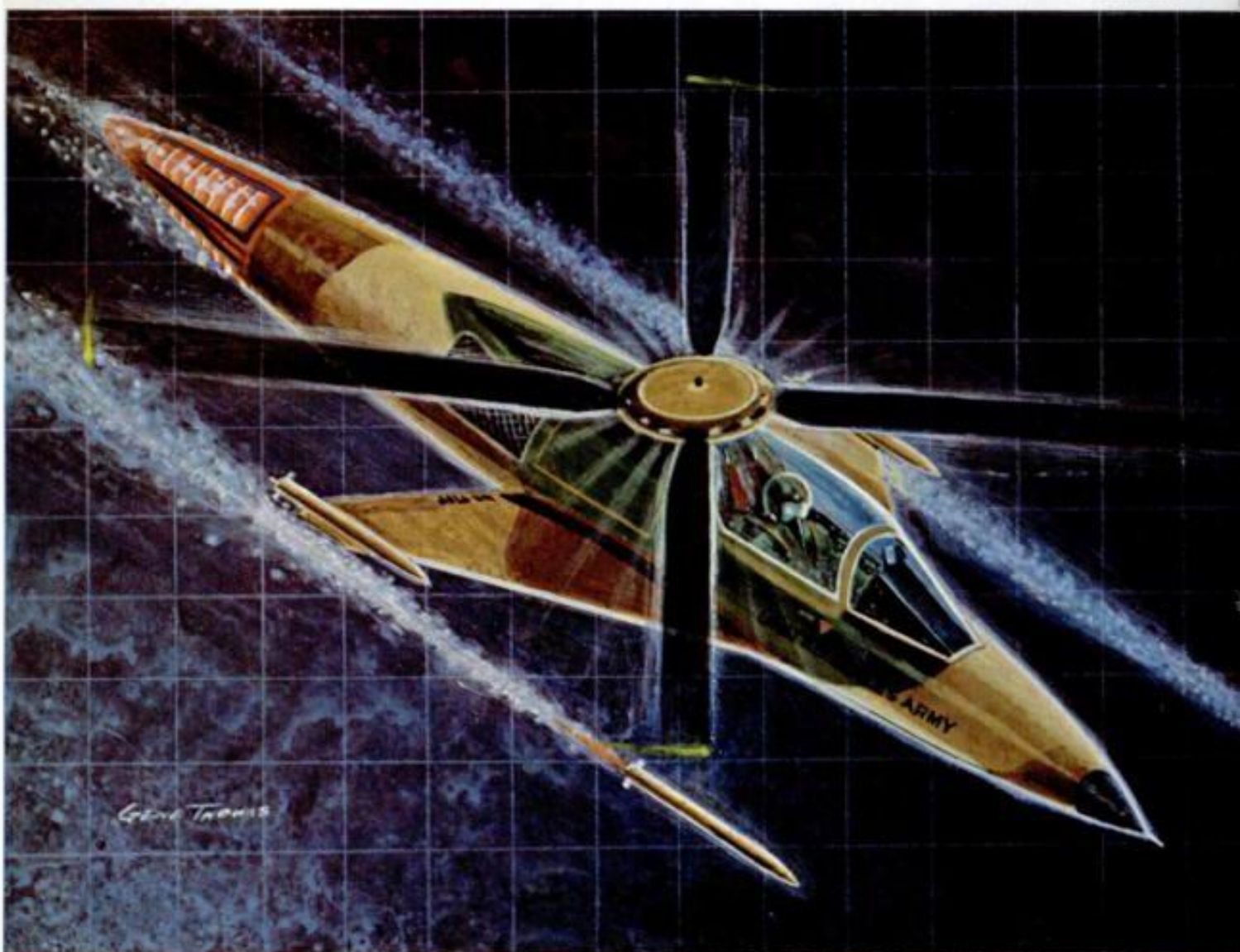
By **CHARLES A. MILLER**
Paintings by Gene Thomas

The helicopter has been used in combat since World War II. It originally was cumbersome, slow, and vulnerable, but it promised

bigger and better things. Now, of course, it's an indispensable part of the U.S. military. To a casual observer the helicopter may not seem greatly altered since its early days, but it's had many evolutionary improvements, especially in reliability.

A quantum change, however, is in the making. The Army is getting ready to build a helicopter—the LHX (light helicopter experimental)—for the 21st century. It may well be the biggest helicopter program in history, costing upward of \$30 billion. As many

Continued





New ideas for helicopters of the future include a hybrid machine that combines wings and rotor (opposite page). When the helicopter is hovering, the wings would rotate down 70 degrees. Also under consideration are a tilt-rotor design (above), which would increase the craft's maximum speed, and an advancing-blade concept machine (at right and below), with counterrotating blades and no tail rotor.

Gene Thomas

Tilt-rotor aircraft

By STUART F. BROWN

FORT WORTH, TEXAS

Wriggling into the right-hand pilot's position in the XV-15, I avoid touching the yellow-and-black grab rings that trigger the emergency ejection seat, and run my eyes over the gauges and controls in the crowded cockpit. Roy Hopkins, one of the test pilots at Bell Helicopter Textron's flight test facility here, leans over my left shoulder to explain how this experimental aircraft with the giant propellers works. Or maybe they should be called rotors? I wonder.

"It's flown very much like a helicopter, with a left-hand collective-pitch lever and a cyclic-pitch control stick in the right hand," he says. "It hovers like a helicopter for take-off and landing—but the button at your left thumb is what makes the XV-15 different from all other aircraft. Push that button forward while hovering, and within twelve seconds the engine nacelles and rotors tilt forward ninety degrees, and it's an airplane. The helicopter controls are phased in or out by a mixer box located in the back," Hopkins continues, pointing toward the tail of the instrument-laden research plane.

Other crew members are sipping coffee and gazing skyward through the gaping door of the hangar, which houses a gaggle of experimental helicopters. It's raining, and there's little chance of clearing. The XV-15 won't be able to fly today, they say. "How come?" I inquire glumly.

"Because of the strain gauges," replies Hopkins. "We have sensors on the rotor blades to measure stresses during flight. Raindrops become very abrasive at rotor-tip speeds of seven or eight hundred feet per second, and chip away at the adhesive that holds the strain gauges on. Centrifugal forces at the ends of the blades get up to a thousand G's, and they tear right off."

On the many days when it doesn't rain in Fort Worth, the XV-15 flight-test program is adding to an already extensive understanding of how best to exploit the part-airplane, part-helicopter characteristics of the tilt-rotor [Feb. '78]. Their work is central to the development of the first production tilt-rotor aircraft, the V-22 Osprey, scheduled to make its maiden flight in June 1988.

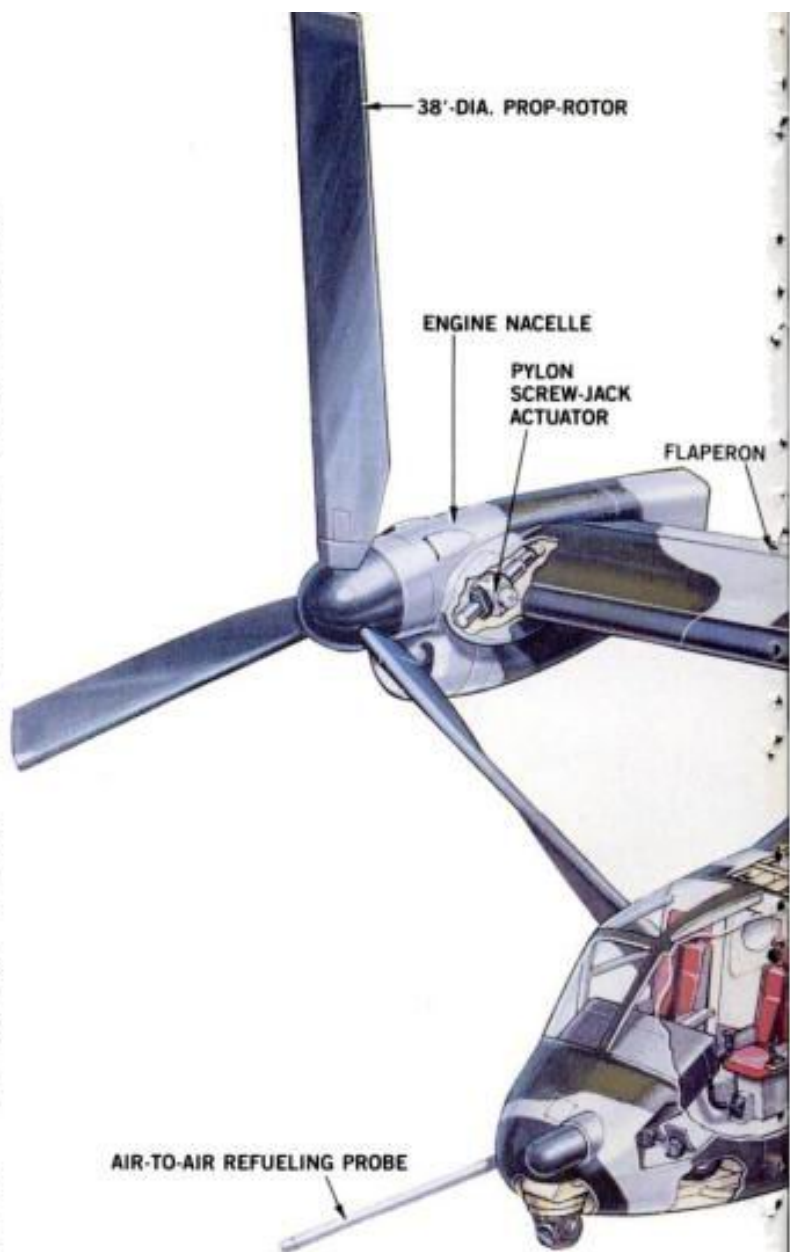
The V-22 is a military transport with an unusual attribute: All four branches of the independent-minded U.S. Armed Forces have agreed that they want to use versions of it. All told, the Pentagon hopes to buy about 1,200 of the \$16 million aircraft, which will be designed and manufactured by Bell in a partnership with Boeing Vertol Co. in Philadelphia. The first ones built will be delivered to the Marine Corps in late 1991 as replacements for their 20-year-old CH-46 Sea Knight helicopters.

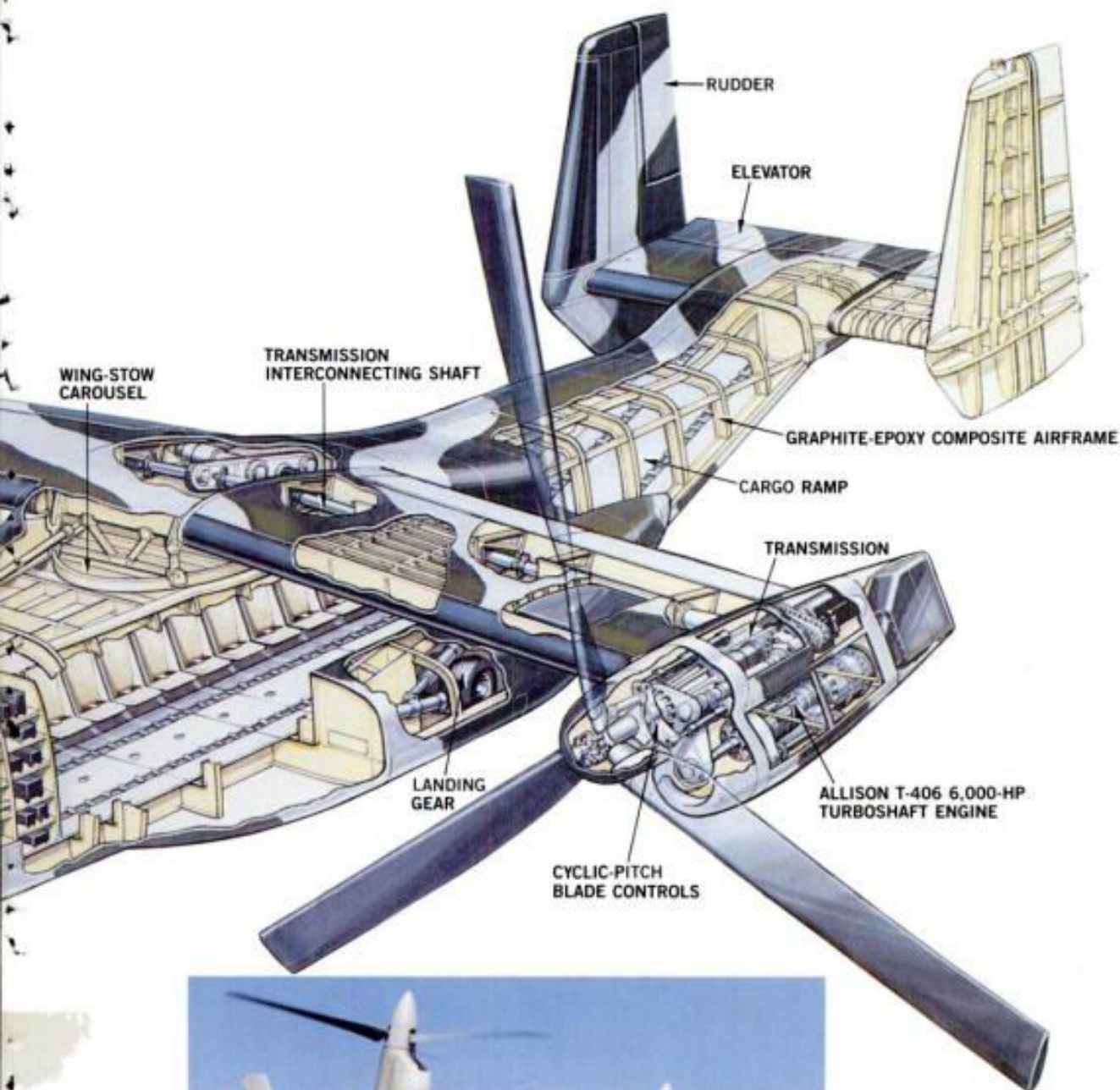
Hush up and move fast

The Marines will use the V-22 to carry 24 combat-equipped troops or up to 10,000 pounds of equipment quickly and quietly into combat from relatively distant ships or bases, according to Col. Harold W. Blot, who manages the V-22 program at the Navy's Air Systems Command in Crystal City, Va.

"An obvious mission for the V-22 is amphibious assault," argues Blot. "With its speed and range, the V-22 will be able to operate from ships at sea far over the horizon [at least 50 miles from the beach], where the enemy can't detect them. That way we can make feints and confuse him as to where we are really going to land. When you do come into the field of fire, the V-22 is going two hundred seventy-five knots—twice as fast as a helicopter. And a

[Continued on page 102]





The hovering Bell XV-15 research tilt-rotor (above) is one of a pair flown since 1976. The much larger V-22 (top) is shown in its airplane mode. During conversion, screw-jack actuators tilt the nacelles upward 90°, and flight is controlled by helicopter-type cyclic-pitch mechanisms. After conversion to the airplane mode the cyclic hardware locks, and pitch, yaw, and roll are controlled by elevators, rudders, and flaperons. If one engine fails, both prop-rotors are powered through transmission-interconnect shafts. For compact storage, the rotor blades fold along the axis of the wing, which rotates on a carousel to line up with the fuselage. The painting (left) shows V-22s converting for vertical landing. A proposed high-speed variant (right) has rotors that fold along nacelles for low drag at 500–600 kts.



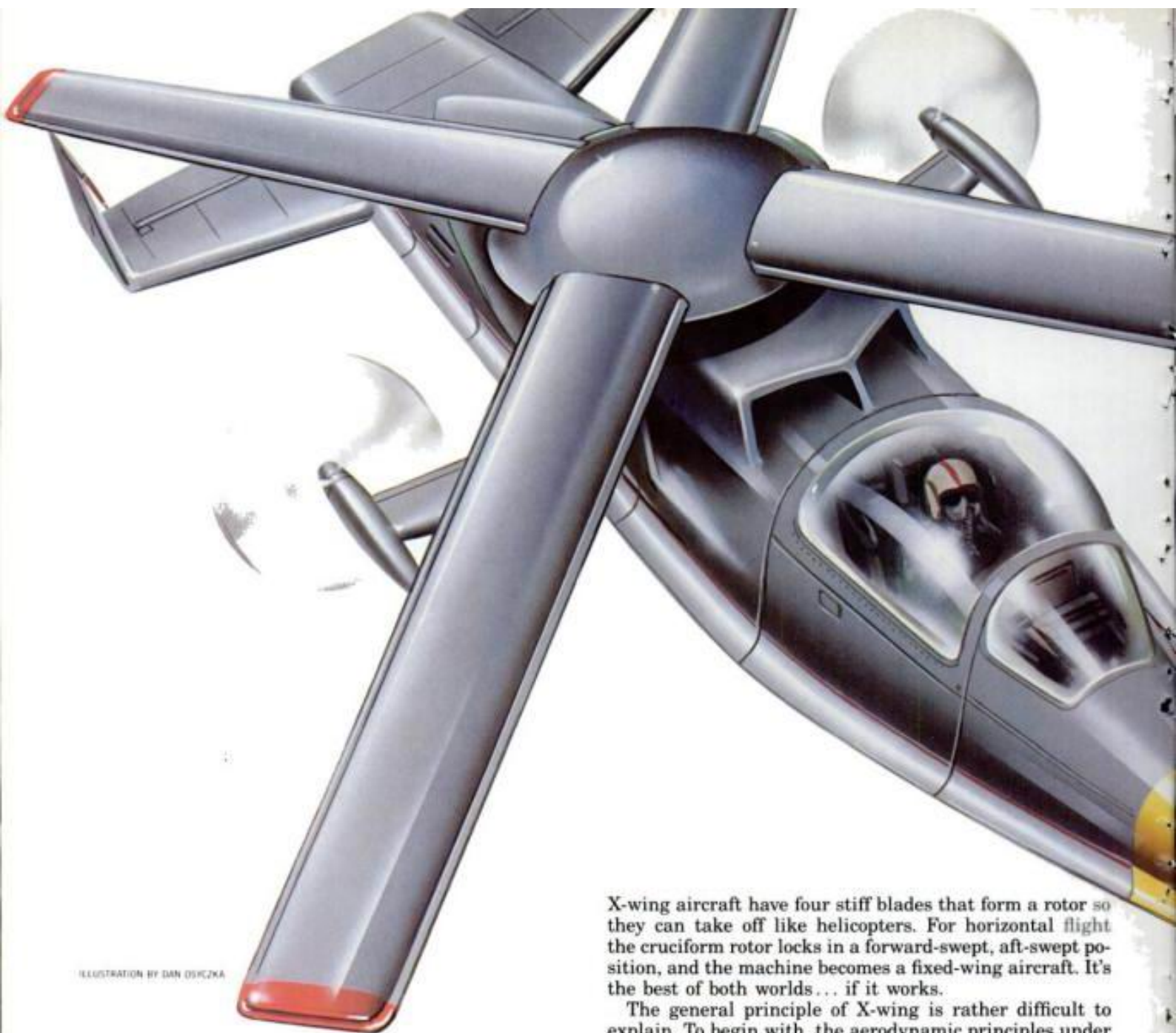


ILLUSTRATION BY DAN OSWICKA

X-wing aircraft

By STEVEN ASHLEY

STRATFORD, CONN.

Click-click... click-click... click-click." Like a chorus of crickets at dusk, the 48 intricate valve mechanisms that form a large high-tech Christmas wreath open and close as Dr. Kenneth M. Rosen hyperkinetically explains the workings of the X-wing aircraft—an advanced type of VTOL:

"This pneumodynamic-valve-actuator apparatus [right] is really the heart of the X-wing," Sikorsky Aircraft's director of advanced vertical/short-takeoff-and-landing programs tells me as he circles the device yet one more time to point out a detail. "By carefully controlling the pressurized-air feed from the compressor to the circulation-control blades [see diagrams at right] while the computer monitors that airflow eighty times per second, this unit controls the lift, trim, and the suppression of vibration for the entire vehicle."

The complicated device I'm looking at, I learn during my visit to Sikorsky's Research and Engineering Center here, is key to a revolutionary plane called the X-wing.

X-wing aircraft have four stiff blades that form a rotor so they can take off like helicopters. For horizontal flight the cruciform rotor locks in a forward-swept, aft-swept position, and the machine becomes a fixed-wing aircraft. It's the best of both worlds... if it works.

The general principle of X-wing is rather difficult to explain. To begin with, the aerodynamic principles under which this craft operates are quite different from those employed in either conventional airplanes or helicopters. So a completely new kind of wing had to be developed.

For decades, engineers have been trying to figure out how to make a single aircraft perform as both airplane and helicopter. The concept of X-wing-type flight has long intrigued engineers, but for years it seemed unfeasible. The reason becomes clear when you analyze what such a craft would have to do. When it flies in the helicopter mode, with its rotor turning, all four blades are advancing in the same direction. When the rotor stops and the plane flies forward, however, two of the blades must fly in the opposite direction. Thus the wing had to be something never before seen in aeronautical science: an airfoil that flies equally well in either direction and that maintains lift even when the airflow over it is slowing down.

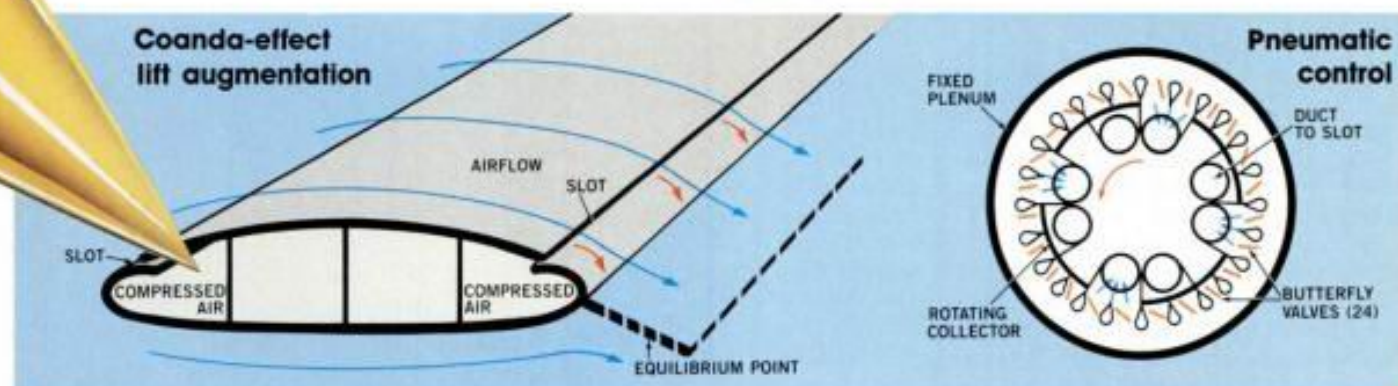
The solution to this problem began to emerge in the early 1960s. A British scientist at the University of Southampton, Ian Cheeseman, proposed using a little-known phenomenon called Coanda-effect blowing to help conventional fixed-wing aircraft take off and land vertically.

The phenomenon had been described by the Romanian scientist Henri Coanda in the 1930s. Coanda found that

[Continued on page 90]

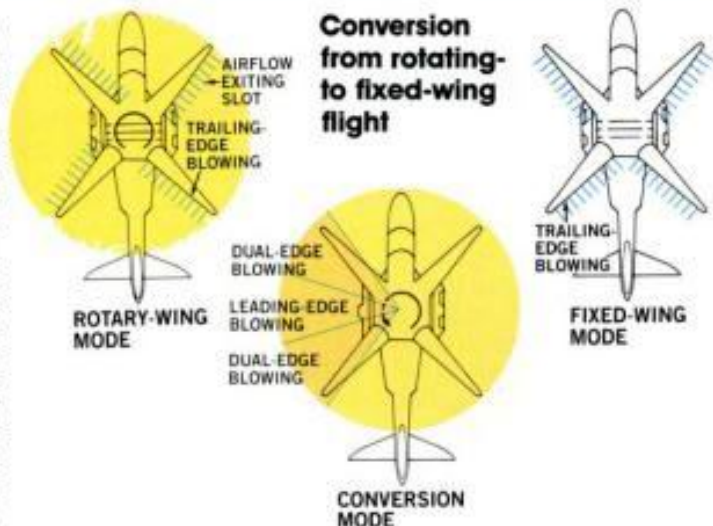


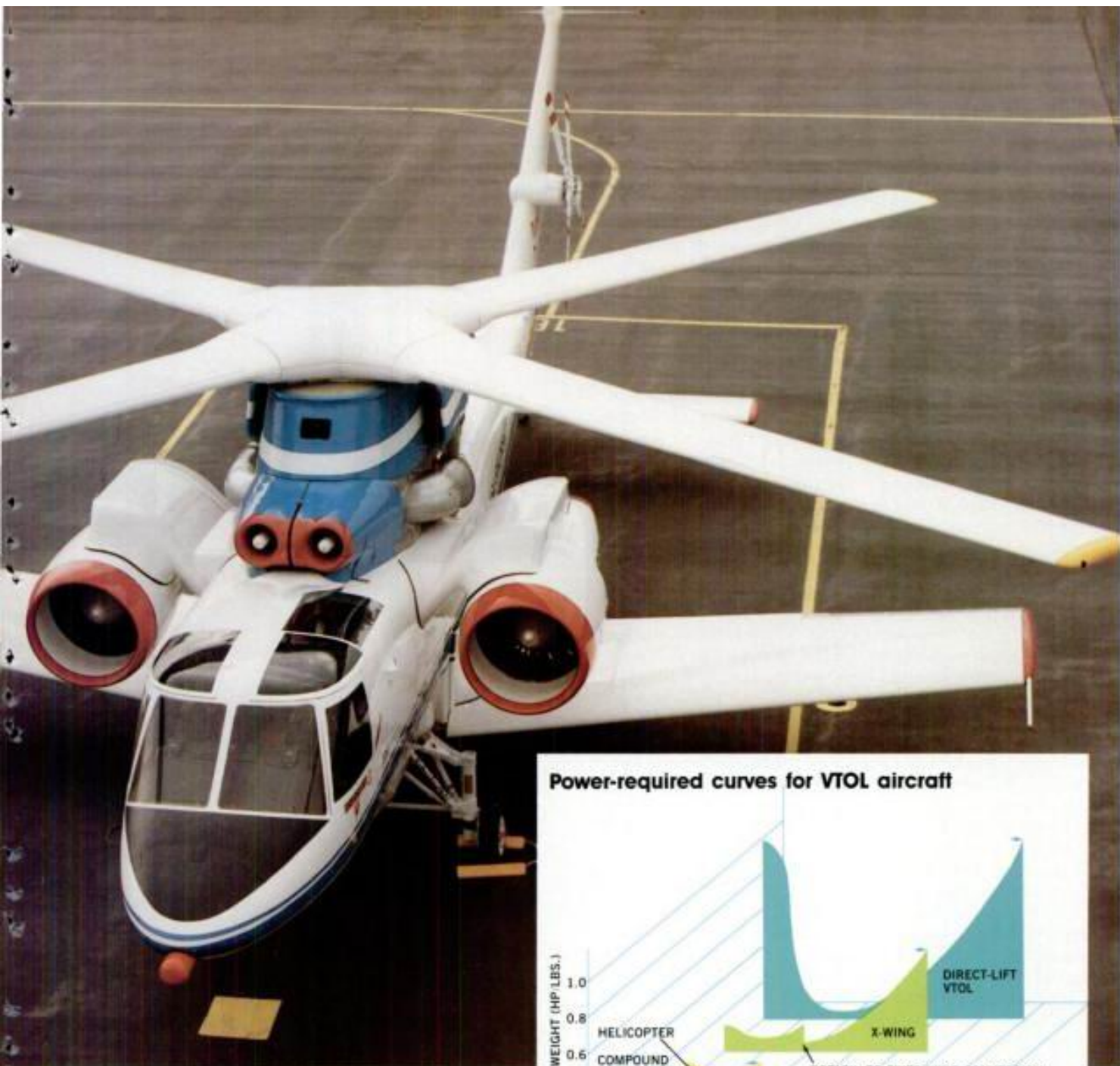
Advanced X-wing aircraft (left) could use shaft-driven pusher props to attain speeds of 400 kts. Engineers believe that a production X-wing may be powered by convertible-mode turbine engines, which can produce either mostly shaft power or mostly thrust as needed. The unique X-wing blades, which contain leading- and trailing-edge slots from which pressurized air is blown, produce four times more lift than do conventional airfoils. Rather than changing the blades' angle of attack in the airstream or moving mechanical flaps to maintain flight control, the mature X-wing system will alter the lift of each blade (in fixed- or rotary-wing mode) by changing air circulation around the airfoils. Large ring (right) is a ground-test pneumodynamic valve-actuator assembly, which controls the flow of air from the compressor to the X-wing rotor blades (diagram below, right).



DRAWINGS BY ELIOT BERGMAN

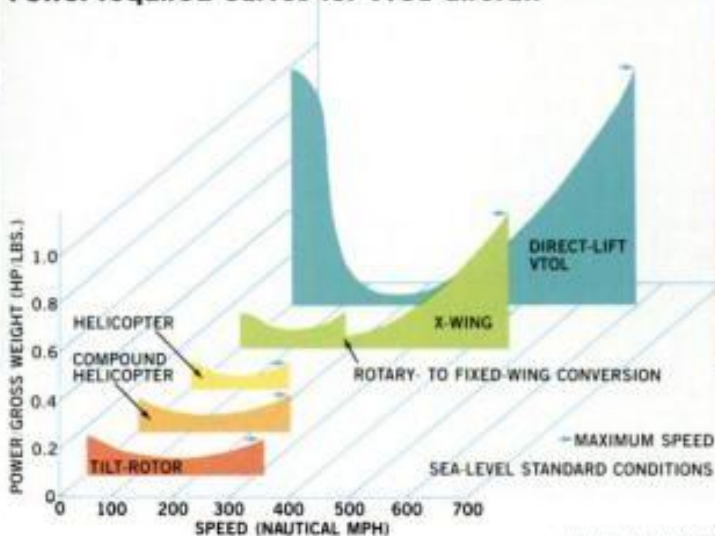
X-wing aircraft rely on circulation-control aerodynamics to provide high lift even at low airspeeds. Unlike conventional airfoils, X-wing airfoils (above left) are symmetrical in cross section (front to back) with rounded "leading-edge-type" profiles and slots from which high-pressure air is blown. Circulation control is based on the Coanda effect—the fact that air forced over a curved surface tends to follow that curve. In addition, the flow entrains surrounding air and accelerates around the curve, creating lift. In effect, the system increases the circulation of air around the airfoil, which, in turn, generates more lift. The pneumodynamic valve system (above right) operates as follows: Air is fed from the compressor to the fixed plenum. Two rows of valves on the plenum's inner wall provide air to the spinning blades' leading- and trailing-edge slots by feeding air to two sets of four receiver ducts as they rotate by. The most difficult part of X-wing flight is the conversion between helicopter and fixed-wing modes (right). As the rotor slows, the retreating side continues to support its share of total lift through leading-edge and dual blowing of the lift-augmentation slots.





The Rotor Systems Research Aircraft/X-wing (above) has auxiliary wings to allow safe testing of the experimental X-wing rotor. The graph (right) shows the power required by various VTOL designs to hover and cruise at different speeds. The power required depends on how much air is propelled how fast.

Power-required curves for VTOL aircraft



GRAPH BY ELIOT BERGMAN



Compound helicopter



Direct-lift VTOL

Lockheed's 1965 *stowed-rotor* concept marries helicopter and airplane, but dual lifting systems and power plants leave little room for payload. In 1958, the Bell XV-3 was the first *tilt-rotor* to convert from helicopter to fixed-wing flight. That same year the Vertol 76, the first *tilt-wing* VTOL, demonstrated conversion by tilting both wings and prop-rotors. Sikorsky's ABC *compound helicopter* attains high speed from counterrotating rotors and auxiliary turbo-thrust engines. The fuel-thirsty McDonnell Douglas/British Aerospace AV-8B Harrier II jump jet has jet-exhaust nozzles that rotate downward for VTOL.

The WHAT'S NEW magazine

SEPTEMBER 1986

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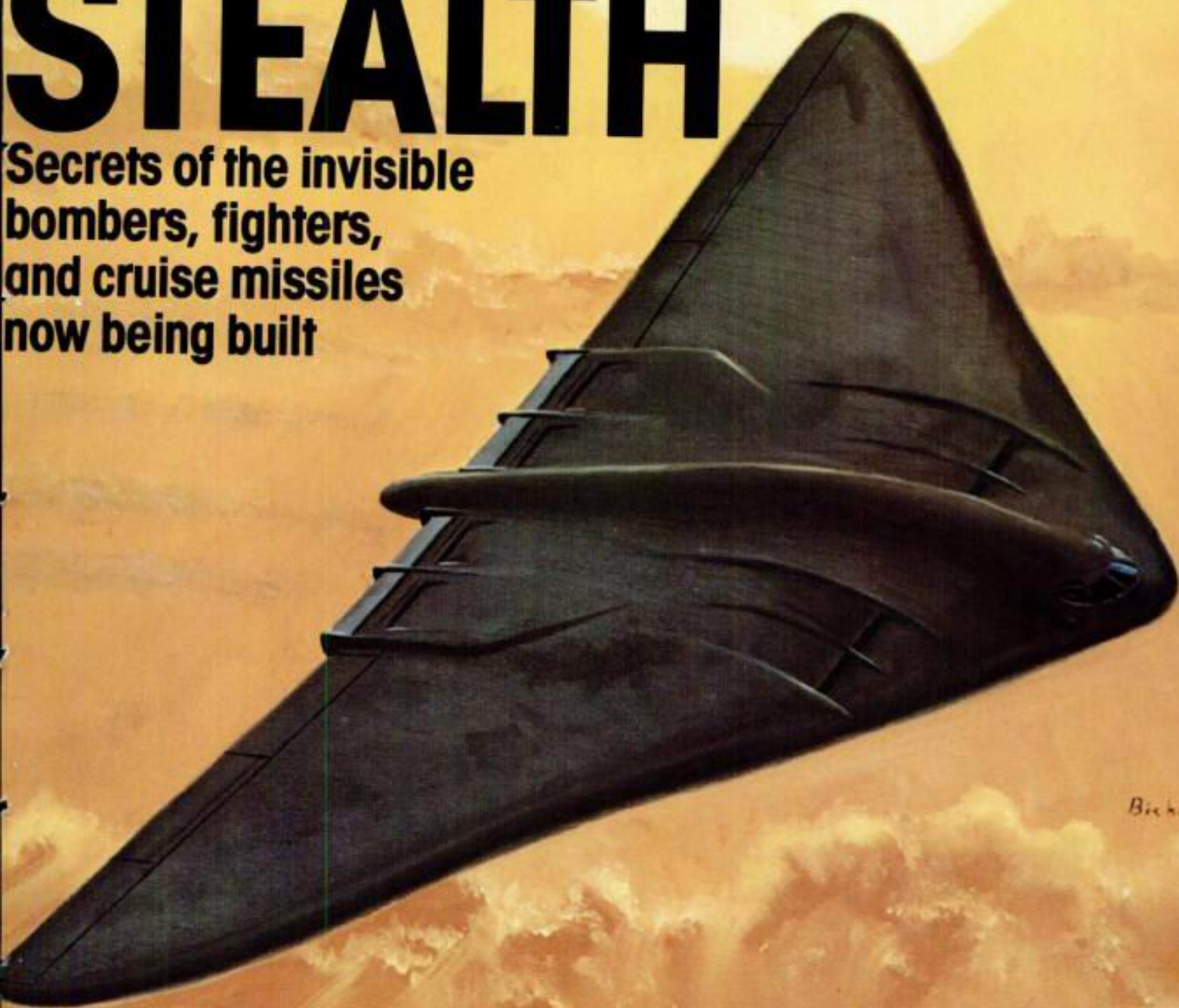
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SPECIAL SECTION: Home & Shop Products & Projects



STEALTH

First glimpses of the invisible aircraft now under construction

By T. A. HEPPENHEIMER

Paintings by Barry Bichler

A secret air force, costing billions of dollars, is now under construction in the United States. It is a stealth air force, and it includes bombers, fighters, and cruise missiles, all designed to be virtually invisible to radar.

The stealth program is a highly classified U.S. Air Force secret. Still, a small cadre of stealth-watching aerospace specialists has assembled data from diverse sources. "Over the years several of us with technical backgrounds have developed a collection of educated inferences concerning stealth technology, based on publications, leaks, congressional testimony, and the like," says John Pike, an associate director of the Federation of American Scientists. Using such information, Pike and others have built up detailed descriptions of stealth techniques, the aircraft, and the missions they will fly.

Other experts have deduced how far research has progressed, how many aircraft have been built, what they cost. They base these projections on factors such as the hiring of workers for unexplained projects and reported revenues from building aircraft for which companies have no known contracts. "How big is stealth?" Alan Benasuli asks rhetorically. "It's probably at least a \$5-billion-per-year industry." Benasuli, a managing director at the investment firm of Drexel, Burnham & Lambert, tracks the aerospace and defense industries. "The fact is, stealth technology touches just about every major aerospace company."

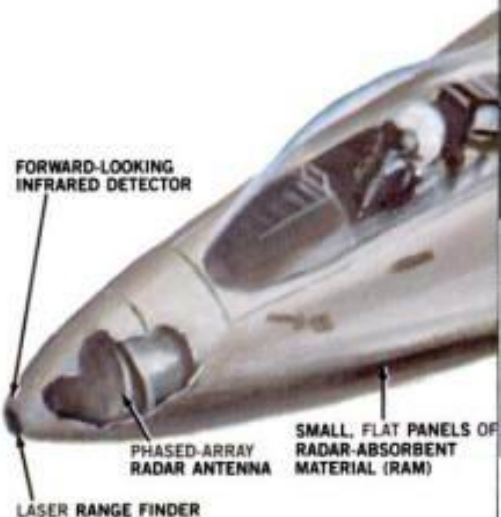
In addition, much-publicized airplanes now in service are showcases of earlier generations of stealth technology. "The B-1B bomber incorporates many stealthy features," observes Pike. "Its supporters are always afraid that their budget will be cut, so they're forever bragging how great it is. That's an important source of information on stealth technology." So is the high-flying and stealthy SR-71 reconnaissance aircraft.

To those outside the black curtain of Pentagon secrecy, making out the stealth picture is like assembling a jigsaw puzzle with only 10 percent of the pieces. Rules of

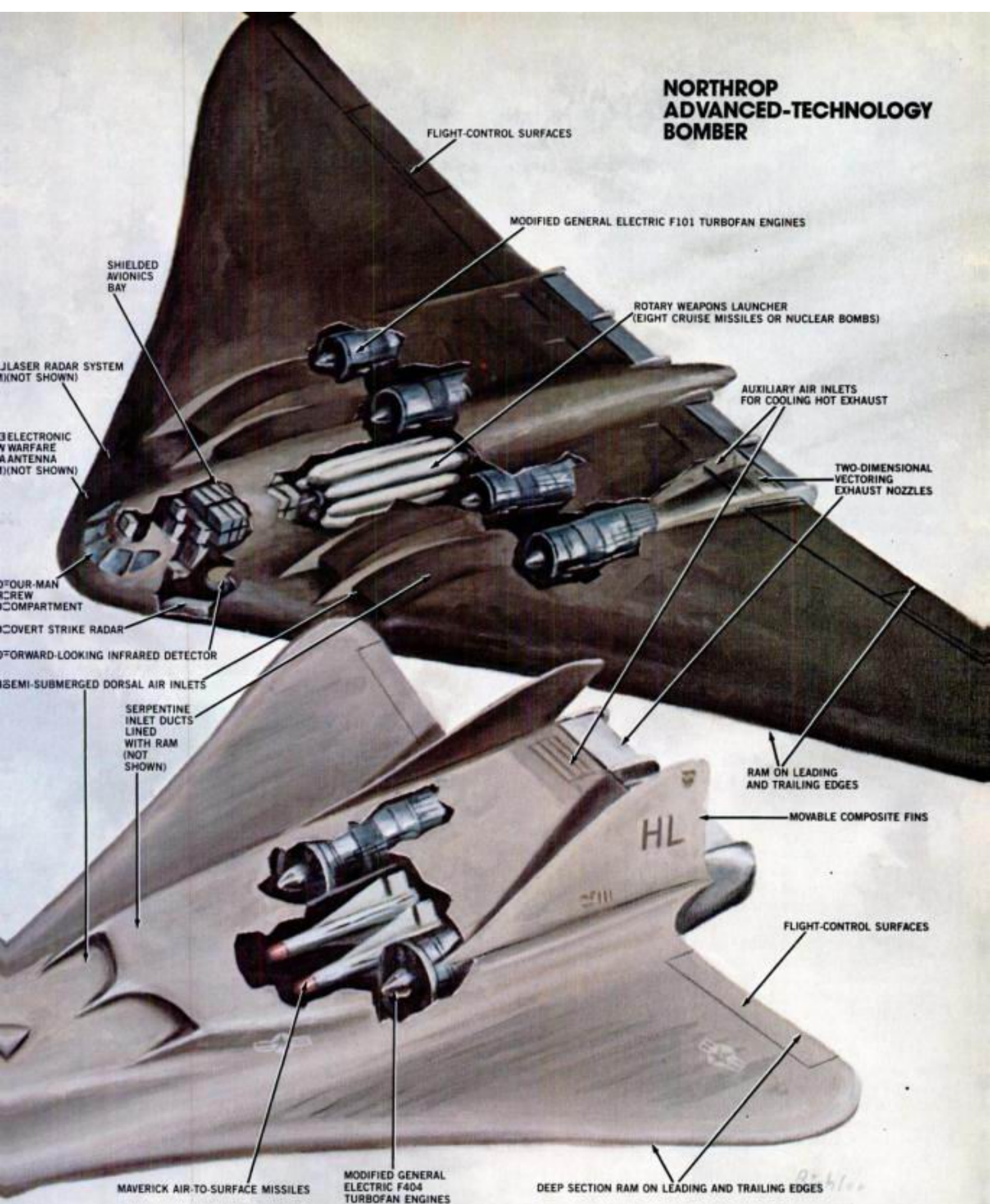
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Shadowy shapes take to the air

Smoothly contoured, almost organic airframe shapes with few openings characterize the designs of the U.S. Air Force's two known stealth airplanes—the advanced technology bomber (ATB) and the so-called "F-19" Covert, Survivable, In-weather Reconnaissance/Strike fighter. The airframes are constructed of radar-transparent and radar-absorbent materials (RAM), with engines, missiles, and other highly radar-reflective metal components concealed deep within the fuselages. The intercontinental ATB is thought to be designed for low-level incursions against "rail-mobile" nuclear-tipped ballistic missile launchers. The F-19's mission is somewhat less clear. Most probably it is to loiter "unseen" near enemy radar installations to conduct surveillance. In battle, the fighter would most likely sneak in close to surface-to-air missile batteries prior to a conventional air attack to knock out their fire-control radar antennas with anti-radiation missiles. It is crucial to the survival of these aircraft that the on-board electronics minimize their electromagnetic emissions, which are easily picked up by the enemy. For instance, the ATB's "covert strike radar" may actually use the enemy's own radar signals to form images of battlefield targets. Likewise, every reasonable measure must be taken to suppress emissions of infrared radiation. Advanced computer-based flight-control systems ensure that these inherently aerodynamically unstable aircraft designs can fly safely and effectively. Special flight-control surface systems make up for undersized or omitted vertical stabilizers. The illustration is loosely based on designs by aerospace journalist Bill Sweetman and aircraft artist Michael A. Badrocke.



NORTHROP ADVANCED-TECHNOLOGY BOMBER



LOCKHEED "F-19" FIGHTER

"To stabilize a flying wing," he continues, "you use a flap that's actuated by gyros. If the plane pitches up by one degree, the gyros sense this and deflect the flap by, say, five degrees to bring it level. You control yaw with a rate gyro, which measures speed of motion. You link it to the rudder, or to the movable wing-tip surfaces that can take the place of a rudder in a flying wing. It's easily handled in the autopilot design." With the stability problem under control, the flying wing—with its low radar cross section—is now much more attractive.

A big problem in designing a stealth aircraft is engine placement. The stealth bomber will probably have the same engines as the B-1B, four F101 turbojets from General Electric. The problem is that the engine's compressor and turbine are excellent radar reflectors, while inlets of con-

ventional design act virtually as conduits for radar waves. Indeed, the radar used on the F-14D and F-15 fighters can actually count enemy compressor blades. This serves to identify the aircraft beyond doubt, at a range approaching a hundred miles. The solution is to bury the engines deep within twisting ducts, which hide them. And ducts and inlets alike can be treated with a coating of radar-absorbent materials.

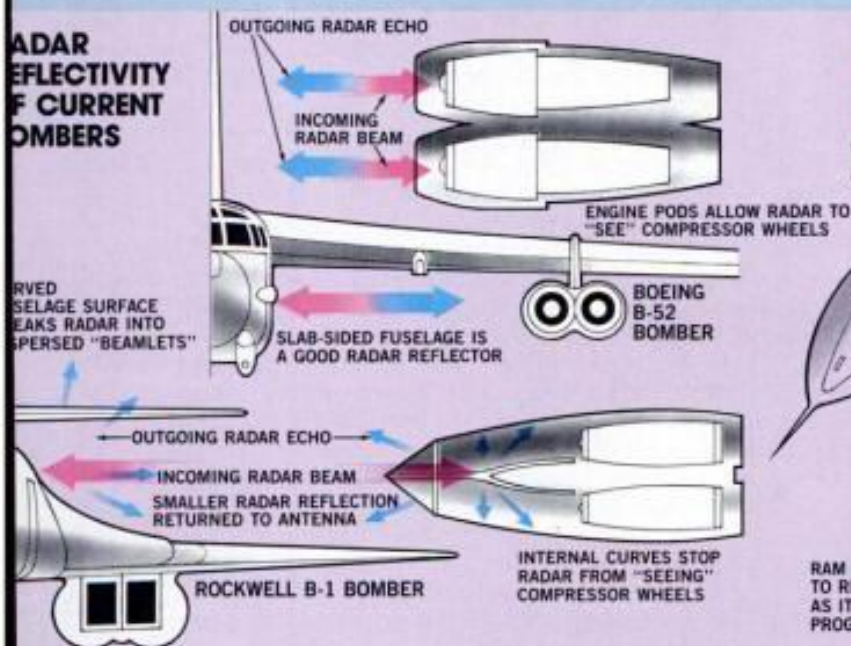
Another way to make a plane invisible to radar is to design it to absorb—rather than reflect—microwaves. A material with this characteristic has come to light in Japan. TDK Corp., largest maker of magnetic recording tape in the world, is an expert in the characteristics of the iron-containing ferrite materials used to coat mag-

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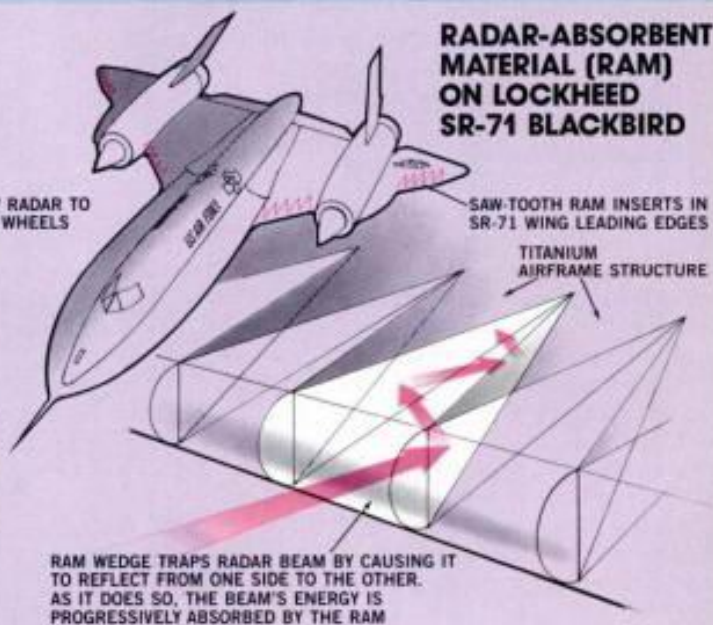


Northrop YB-49, a flying wing with a 172-ft. span, is said to resemble the stealth bomber. It first flew in 1947.

ADAR REFLECTIVITY OF CURRENT BOMBERS

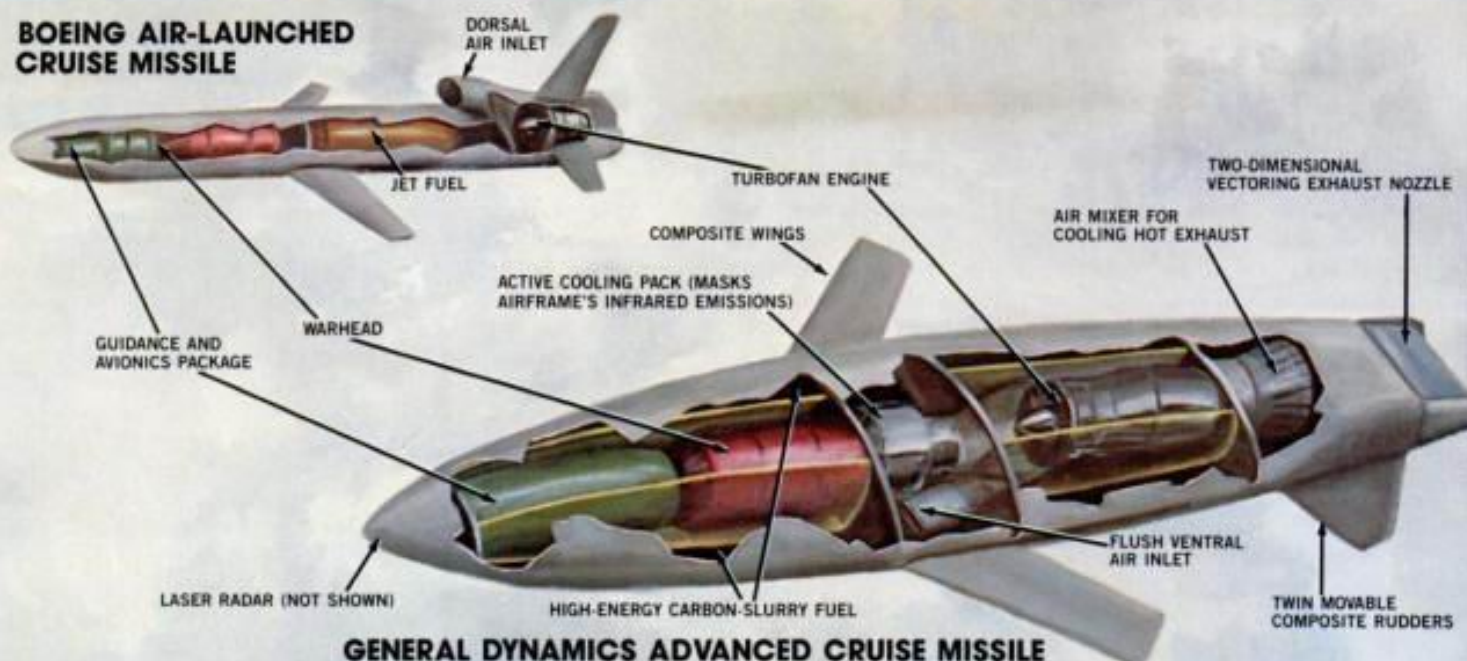


RADAR-ABSORBENT MATERIAL (RAM) ON LOCKHEED SR-71 BLACKBIRD



DRAWINGS BY ADOLPH BROTMAN

BOEING AIR-LAUNCHED CRUISE MISSILE



GENERAL DYNAMICS ADVANCED CRUISE MISSILE

Conceptual design developed by aerospace journalist Bill Sweetman and aircraft artist Michael A. Sedrook.

The U.S. Air Force/General Dynamics advanced cruise missile, or ACM (foreground), is expected to make extensive use of stealth technology. The prominent dorsal air inlet, metal airframe, and large fin of Boeing's earlier air-launched cruise missile or ALCM (background) make it a larger-than-desired radar target. The ACM, which is to supplant the ALCM, presents a much smaller target to radar and infrared sensors by virtue of a ventrally mounted flush air inlet, an exhaust nozzle that suppresses infrared emissions, an

air-mixing system to cool exhaust gases, and detachable, non-radar-reflecting composite wings. High-energy-content fuel burned in an advanced Williams International F112 turbofan engine is expected to give the ACM greater range. For guidance, the ACM may make use of pulsed-laser radar systems under development by Hughes Aircraft Co. and McDonnell Douglas Corp. These thin-beam, high-resolution optical devices would make detection by enemy sensors less likely. The ACM will reportedly enter service in the late-1980s.

netic recording tape. But ferrites are not just magnetic, they also absorb microwaves. In fact, TDK has stuck ferrite tiles on some tall buildings to absorb TV signals and kill ghost images on home TV screens. The company has also used the same material to stop leaks from microwave ovens. And because metal bridges reflect strong and sometimes troublesome signals to marine radar, TDK researchers developed a plan to paint bridges with this material to reduce their radar echoes. They used two layers of ferrites with different characteristics. The mixture was effective in absorbing signals over a wide frequency range.

Ideally, of course, stealth planes could be built of materials that were in themselves absorptive of radar waves. "We'd like to find radar-absorbing materials that have great structural strength, so that they're not parasitic," says Col. Albert C. Piccirillo, manager of the Air Force's Advanced Tactical Fighter (ATF) program, which is developing a future aircraft that will embody stealth characteristics. "One of the early radar-absorbing materials was a hunk of rubber loaded with steel balls. That's just dead weight." A better approach is to make use of lightweight composite materials such as carbon-epoxy and Kevlar aramid-epoxy. These are excellent radar absorbers, soaking up an incoming beam and reflecting little back. In addition, iron filings and needles can be incorporated into such material. The iron particles absorb the electromagnetic energy of the radar waves.

Just how the important ingredients of shape and absorptive materials can interact to make a plane stealthy was outlined by an expert in the field, John Hansman, assistant professor of aeronautics and astronautics at the Massachusetts Institute of Technology. "Smooth contours instead of sharp edges and angles are what you want for

less visibility to radar. RCS is an interaction of the airplane's reflectivity and absorption—which are a materials issue—and its directivity, which is a shape issue. Where will the shape make the reflections go? If you don't think about this from all views of the airplane, you can have a design that's clean looking from the front, but dirty looking from the side."

Reports indicate that extensive use of plastic composite materials such as carbon-fiber epoxies is in fact a key element of stealth technology. "A metal has a high reflectivity and a low absorption rate, so it reflects most of the microwave energy in a radar beam back to the source," Hansman says. "But carbon is a good absorber of microwave energy. When microwaves hit a piece of carbon, most of the energy is absorbed and the carbon just warms up a little. Ferrite materials do a similar thing. The ferrite materials work on interfering with the magnetic field, and the carbon works on cutting down the electrical field. An electromagnetic wave is a combination of both, so if you can absorb energy out of one or the other, you've cut back on the wave."

"If you lace some carbon or ferromagnetic material into the structure of your airplane, you increase its absorption of radar," he continues. "My guess [at stealth strategy] is that—since there will always be some metal in an airplane—if you can absorb all of the microwave energy at the surface of the craft, then it will never get into the metal parts and reflect back. The radar will never know the pulse was soaked up. It will think the pulse just kept going and didn't strike anything."

The exact form of the coating or materials containing absorbing particles will have an important effect on performance. "The thickness of the coating or the size of the

particles depends on what radar frequency you're dealing with," says Pike. "Radar-absorptive material thus is a lot more effective against high-frequency radars than against low-frequency ones. Thus the plane actually becomes more difficult to detect as it gets closer to its target."

This puzzling circumstance grows out of the fact that the main long-range Soviet radar systems use low frequencies and thus might see the stealth aircraft. But these search radars then must hand off their images to local fire-control radars. These operate at higher frequencies—and they may fail to spot the stealth aircraft clearly. Interceptors in flight use even smaller radar systems with higher frequencies, and anti-aircraft missiles use the smallest radars of all. Thus these two may be the easiest to "spoof," as airmen put it. Indeed, Air Force Secretary Verne Orr has given an assessment in *Aerospace Daily*: "The whole thrust of stealth is to be able to get through the fire-control radars, not the search radars."

Not only radar-absorbing materials and coatings can be used to absorb radar; the underlying structure can also be designed to help. Much of the testing of radar and other microwave devices is done in rooms called anechoic chambers. Thousands of steep pyramids of radar-absorbing materials line the entire walls of such chambers. Microwave energy hitting these walls bounces back and forth between the pyramids and is absorbed almost completely. The same principle can be applied to stealth aircraft. John Andrews reaches into a bookshelf, pulls out a blue loose-leaf folder, and shows a photo of the leading edge of an SR-71 wing. Now Andrews rummages through his folder and finds a patent dated 1958, titled "Microwave Radiation Absorber." It shows a scalloped and deeply indented pattern of ferrite material, rich in tiny iron particles, with wedge-shaped inserts of material that will not conduct electricity. The resemblance to the SR-71 wing is striking.

Using information such as this, it is possible for a knowledgeable person to take a stab at designing—at least in principle—a stealth aircraft. Bill Sweetman is technical editor for two European aerospace publications, *Interavia* and *International Defense Review*. He has recently written a book, *Stealth Aircraft*. "My concepts are based on reports in the aerospace and military press, which have

been pretty consistent during these years," he says. "I changed one design after talking with someone who'd talked with someone who'd had an eye-witness report." Still, as he emphasizes, the most important thing is a detailed understanding of how aircraft are laid out, with cockpit, weapons bays, fuel tanks, and the like. He has worked closely with Mike Badrocke in England, who makes cutaway drawings of aircraft for *Flight* and *Air International* magazines.

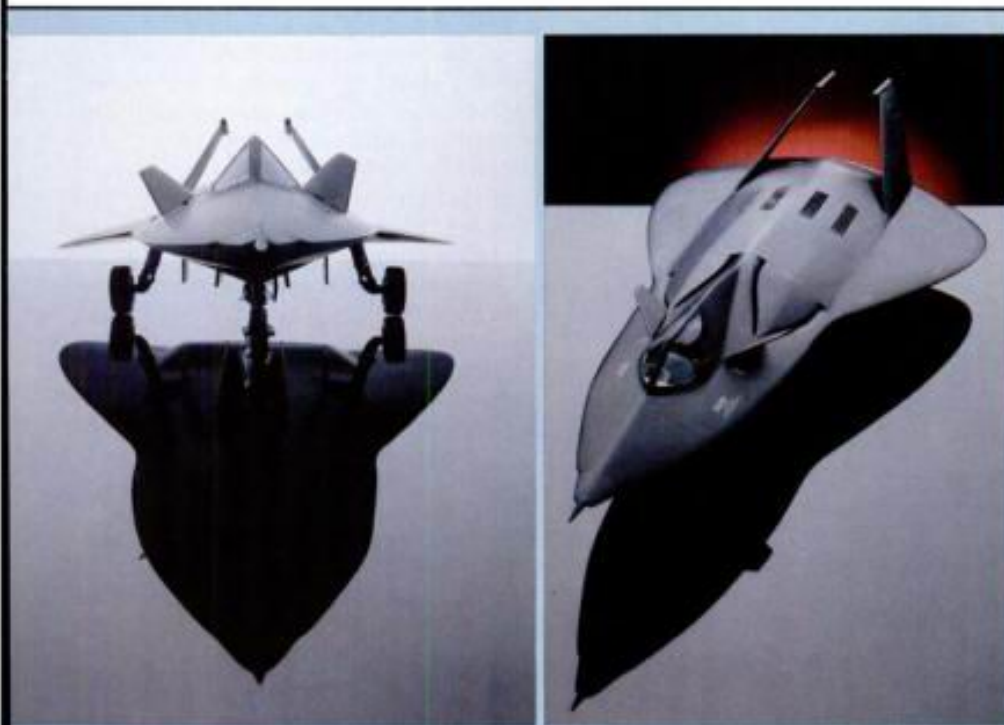
His design for a stealth fighter is 60 feet long, with a double-delta wing rather like that of the space shuttle. He puts much emphasis on hiding the engines and their exhausts: "Curving or S-shaped ducts are well known; Lockheed built the biggest ones, for the TriStar jetliner."

At the plane's tail he uses a standard "two-dimensional" nozzle like that which the Air Force expects to install on its new ATF. It has flat panels at top and bottom that move to deflect the exhaust, adding maneuverability. Sweetman's design adds inlets that mix in outside air to cut the infrared emissions. For further protection, he puts baffles across the rear of the nozzles: "If you baffle the exhaust, you reduce radar reflections from the rear."

While stealth planes will return only small radar echoes, they will also be equipped to jam them. Today's bombers carry extensive electronic countermeasures gear—ECM. ECM jams enemy radars by laying down a barrage of noise that swamps their receivers, or it may rebroadcast a deliberately modified signal to spoof the enemy. But with the advent of ever-more stealthy planes, the need for ECM is not as critical. Gen. Robert D. Russ, who was at one time deputy chief of staff for research, development, and acquisition and then commander of the Tactical Air Command, testified before a closed session of the House Armed Services Committee last year. The testimony was later made public. The Boeing B-52 "has such a large radar signature," he said, "that it primarily depends on tactics and ECM to survive. As you move to the B-1 and we introduce an element of stealth, you rely on stealth and ECM, also some tactics. And when you move to the ATB, you again rely on more stealth and possibly some ECM."

Still, radar isn't the only way to detect an aircraft.

(Continued on page 115)



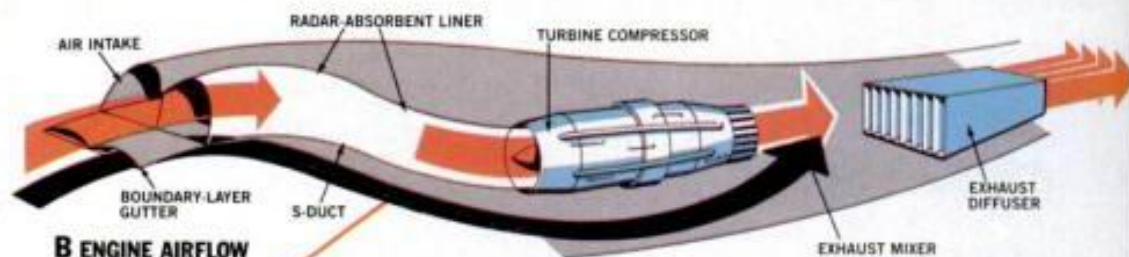
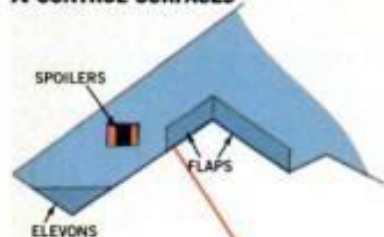
PHOTOS BY ROY RETOLA

Model shop secrets

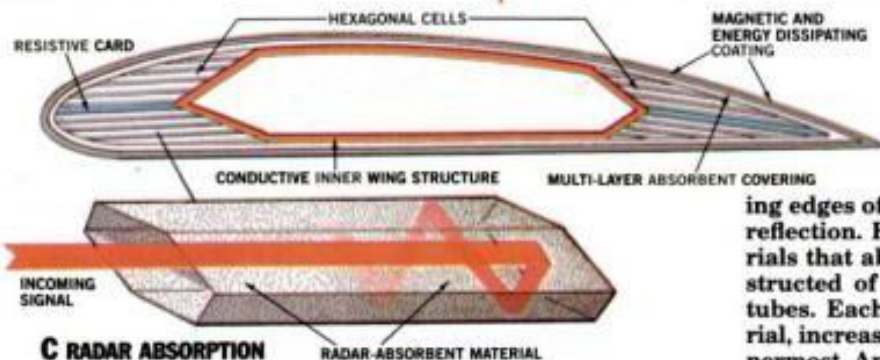
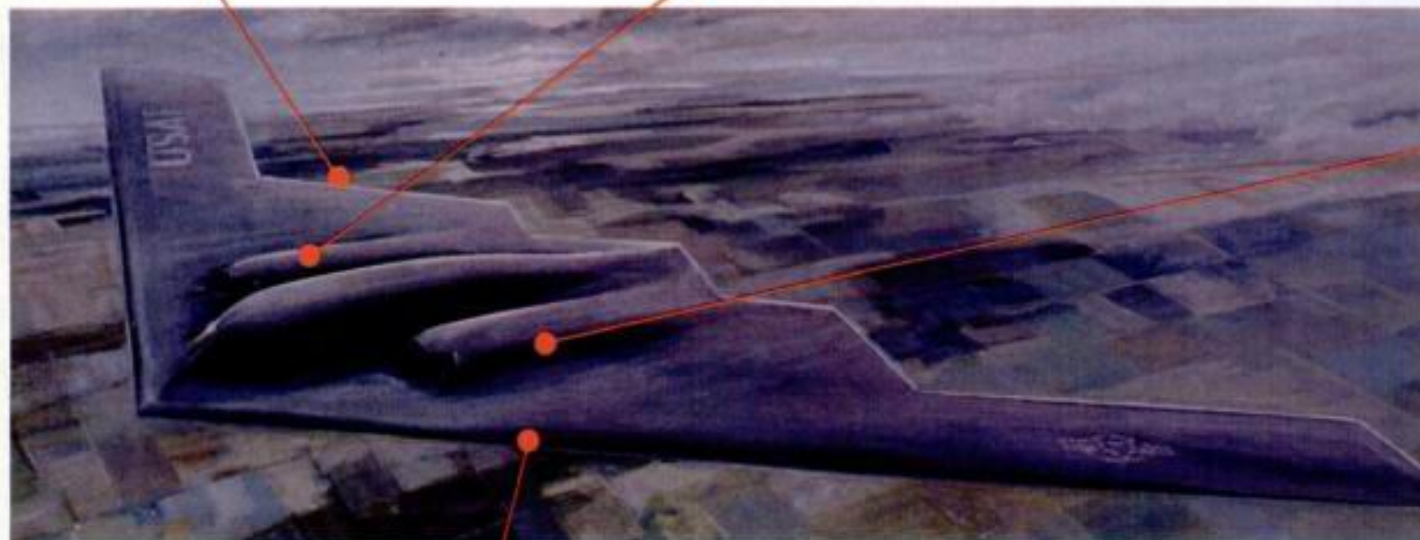
In July, plastic models of the Air Force/Lockheed stealth fighter hit U.S. model shops. Though no one at Testor Corp. has seen the Lockheed aircraft, the model company's officials reportedly said that all indications are that the design closely resembles the actual fighter. John Andrews, the model's designer, explains how it came about: "We started with print reports that the power plant consists of two General Electric F404 engines, without afterburners. We took the dimensions of that engine, then we designed in the elements that an aircraft must have, taking care to account for its center of gravity. We applied these considerations to a fuselage resembling the SR-71, but we made the fuselage larger [to hide the engines by placing them behind twisting ducts lined with RAM]. The result is pretty much an SR-71 fuselage with a wing planform from the *Radar Cross-Section Handbook*."

What the Air Force isn't saying—critical elements not shown

A CONTROL SURFACES



B ENGINE AIRFLOW



C RADAR ABSORPTION

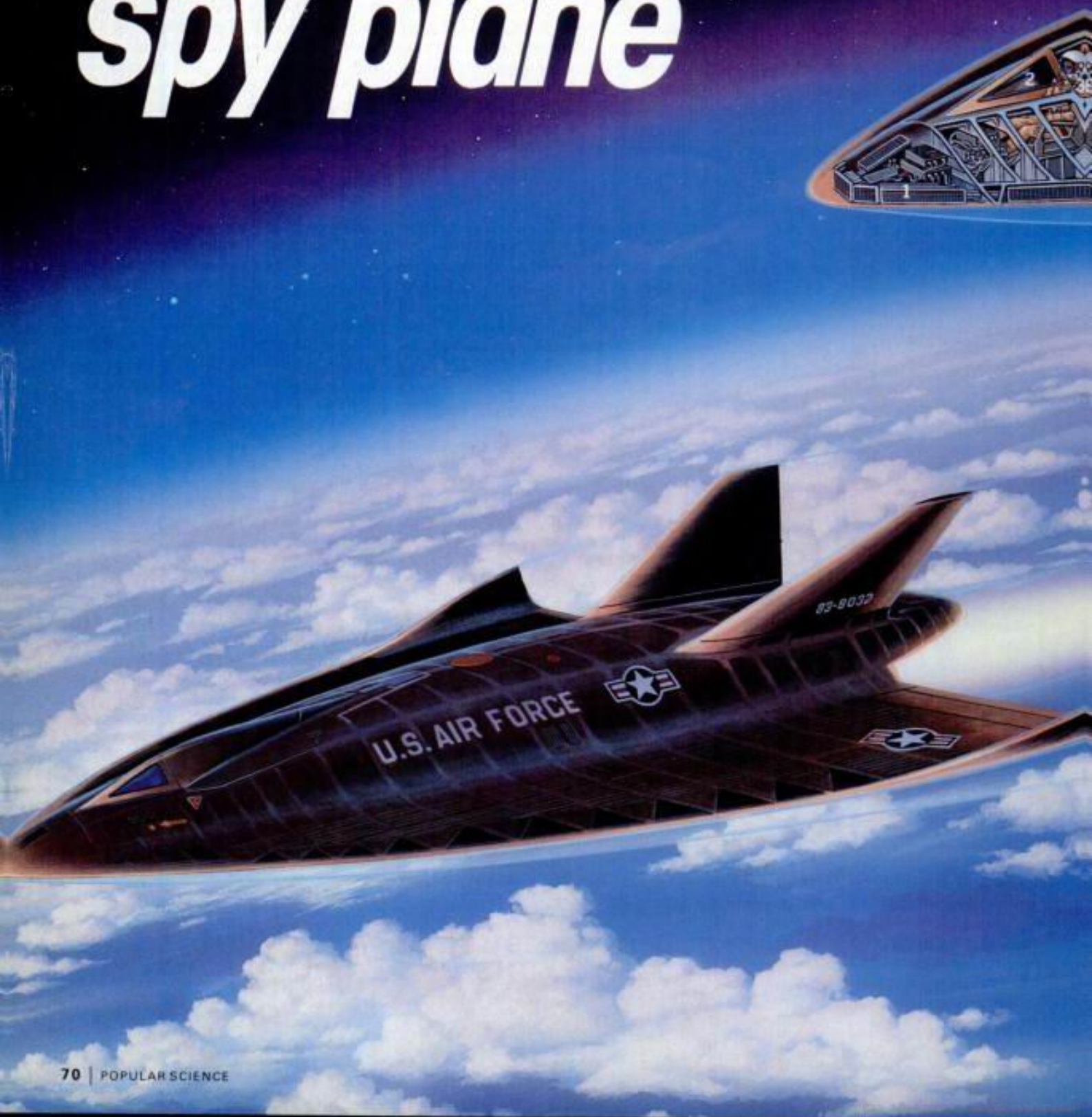
RADAR-ABSORBENT MATERIAL

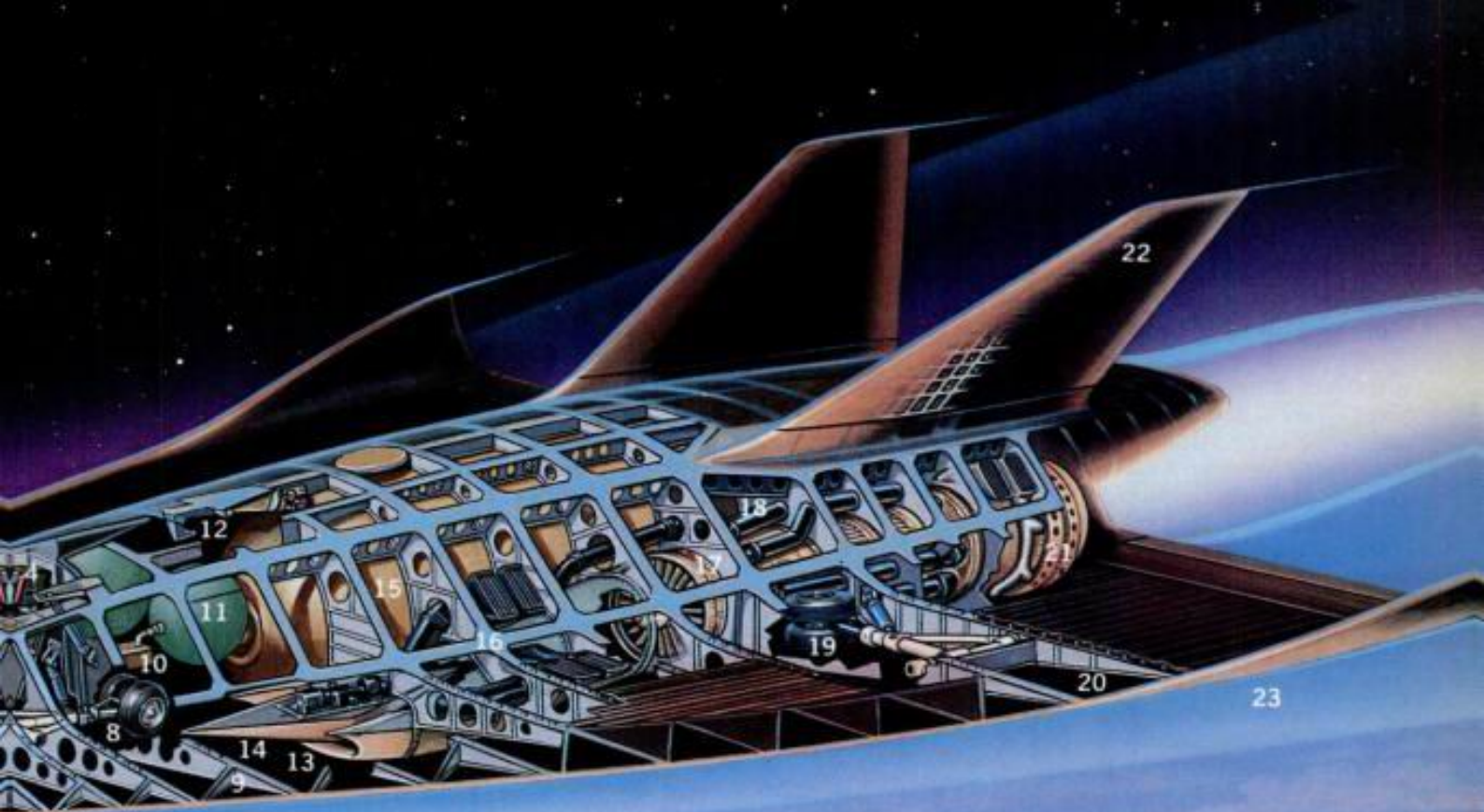
ROCKWELL INTERNATIONAL SCIENCE CENTER

The official painting of the B-2 released by the Air Force (above) shows a boomerang-shaped structure with a saw-tooth trailing edge and three raised pods on the wing. Two are obviously for engines, the third is for crew and probably weapons. No control surfaces are shown. Experts guess that in the absence of any vertical stabilizer, directional control (A) might be achieved with elevons on the wingtips. Spoilers raised on one wing and not the other might introduce drag on one side, thus initiating a turn. Flaps might be mounted in the most forward parts of the serrated trailing edge, because that would put them closest to the center of gravity, where they would have minimum effect on pitch. Engine mounting is critical (B). Air probably flows through the intakes on top of the wing through an S-duct to the engines. Thus the engine compressor—a strong potential source of radar echoes—is hidden from incoming radar signals. A vaned diffuser flattens the exhaust jet into a thin, wide plume, making it harder to spot by satellite-borne heat sensors. A thin additional inlet called a boundary-layer gutter can be seen below each main inlet. These probably serve two purposes. First, a layer of turbulent air near the top surface of the wing can be bled off through this inlet, smoothing the flow into the engine. Second, the additional air is mixed with the jet exhaust, helping to cool it, further reducing the chance of IR detection. The leading and trail-

ing edges of the wing (C) are constructed to minimize radar reflection. First, they are covered with multilayered materials that absorb radar signals. Second, the edges are constructed of a series of thumb-size hexagonal honeycomb tubes. Each hexagon is filled with radar-absorbing material, increasing in density from the outermost edge to the innermost. An incoming radar signal first strikes and is partly absorbed by the multilayered covering. The rest goes into a hexagonal cell. As it penetrates, it continues to be progressively absorbed. The remaining signal that strikes the angled surface at the rear is reflected in a zigzag pattern back through the cell, continuing to be absorbed along this even longer path. Such a technique might nearly eliminate radar reflection from the wing edges. "It's a Roach Motel for radar waves," said one observer. "They check in, but they don't check out." Although it is not shown in the official Air Force version, some experts think the wing-top pods will be faceted rather than smoothly contoured (D). When a radar signal strikes a normal contoured surface of the kind found on most aircraft, a glint is transmitted back in almost any direction, making the target easy to see on radar. A faceted surface, on the other hand, tends to reflect signals in directions slightly different from the direction from which they came, so they do not return to the originating radar. The surface, of course, would also be coated with radar-absorbent material to reduce reflections in any direction. One possible countermeasure that might be applied against a stealth aircraft is bistatic radar, in which the transmitter is at one location and the receiver at another (E). The signal transmitted by either ground or satellite transmitter can ricochet off the target and be received by a separate ground receiver. Another advantage of this arrangement: The listening ground station is passive; because it is radar-silent, its location cannot be determined by the attacking plane.

REVEALED! **Mach 5** **spy plane**





Authoritative sources say the U.S. Air Force is developing a radar-evading reconnaissance plane that will fly five times the speed of sound at altitudes exceeding 100,000 feet. Aurora, as it's called, will replace the SR-71 Blackbird, the world speed and altitude champion. How would Aurora be built? *POPULAR SCIENCE* went to hypersonic-aircraft designers to find out.

By **T. A. HEPPENHEIMER**

Illustrations by Mark McCandlish

The U.S. Air Force C-5B transport plane, one of the world's largest, wings its way through early morning darkness 35,000 feet above the North Pacific. Several hours earlier, the aircraft lifted off from a restricted airfield in Alaska. Now far at sea, it is alone, remote from ships, planes, and land.

With a whine of electric motors, the aircraft's aft clamshell doors open. Like a butterfly emerging from its cocoon, a slim black shape slides out the back. Cables steady it until it clears the doors. For a few moments, it hangs suspended from an extendable arm similar to an in-flight refueling boom.

The object is an airplane, wings folded and engines idling. Suddenly,

the wings deploy and lock into position. Cables and boom disengage abruptly, and the craft falls free. The mother ship now banks away sharply, leaving its spawn alone in the empty black sky.

Inside the newly launched plane's cockpit, the pilot pushes the engine throttles to full power. Long cones of white-hot flame stab backward from the exhausts, and the dusky dart leaps skyward. It climbs at an angle far steeper than that of any airliner.

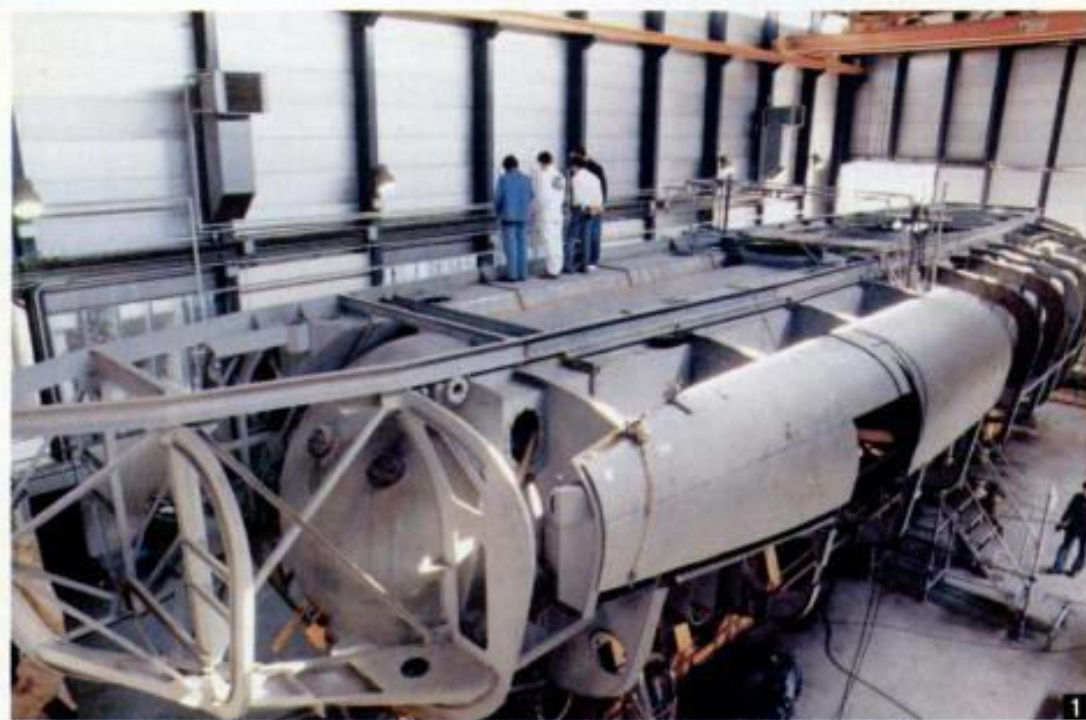
The pilot does not notice the thin blue line that forms along the eastern horizon—the first glow of dawn. Nor does he notice the blue line begin to arc, revealing Earth's curvature. Minutes later, also unmarked, the blue arc fades to black as the airplane outraces the dawn.

Guided only by instruments, the

plane hurtles into the indigo void at five times the speed of sound—Mach 5 or 3,800 mph—more than twice the

Continued

(1) Phased-array radar; (2) heat-resistant glass windshield with retractable heat shield; (3) pilot; (4) reconnaissance officer; (5) slit-scan radar; (6) infrared and photo-optic surveillance sensors; (7) viewing port with heat shield; (8) nose landing gear; (9) sawtooth-shaped radar-absorbing material; (10) flight-control avionics; (11) oxygen tanks; (12) in-flight recovery hook and refueling receptacle; (13) engine inlet; (14) movable inlet spike; (15) methane or hydrogen fuel tank; (16) heat-resistant titanium-aluminide-alloy airframe and skin; (17) turboramjet engines; (18) engine bypass ducts; (19) main landing gear; (20) radar-absorbing skin coating; (21) ramjet afterburner; (22) vertical stabilizer; (23) shock wave.



Drawing of *Saga I* (top) shows observation post in bow. Spherical escape capsule and pilot station for remotely operated vehicle lie above central navigation controls. Below is a diesel engine (blue) and two 100-hp Stirling engines (red). Behind the engine room are the diver control room, transfer lock, and diver lock-out compartment.

Hydraulic thruster juts from stern. **1** First model, shown during construction at the Comex shipyard, has a drag-reducing steel skin encasing the cylindrical pressure hull. Top speed underwater is a modest seven knots. **2** The heat-insulated combustion chamber of each Stirling sub engine is enclosed in a domed pressure vessel. High



pressure allows release of exhaust. **3** Inside the engine, four cylinders are arranged in a compact V-formation. **4** Connecting tubes join the top of each cylinder to the bottom of its neighbor, and a small volume of working fluid (helium) moves through the closed circuit. The upper parts of the tubes are heated by the external combustion

Stirling-powered sub

Stirling engines, invented 172 years ago, now enable non-nuclear commercial submarines to remain underwater for extended missions—including explorations for minerals and oil.

By DAVID SCOTT

Until recently, only submarines driven by nuclear reactors were able to remain underwater for weeks at a time. But a submarine just launched in Marseilles, France, is proving that nuclear power isn't necessary for prolonged expeditions. *Saga I*, the largest commercial submarine ever made, can stay in deep seas for more than three weeks and cover up to 150 miles without surfacing.

The 92-foot craft will inspect oil rigs, probe possible drill sites, and explore the sea bottom for minerals. The sub can roam freely under ice packs, and it costs less than surface vessels now used to support divers released in deep, rough seas.

Comex, the French company that built *Saga I*, delved into history for the sub's power source. Invented in

1816 by a British clergyman, the Stirling engine has been the centerpiece of a number of abandoned projects, including several experimental automobiles [June '71, Feb. '73, June '74, June '78, Jan. '83]. The Stirling's allure: It operates by external combustion—ideal for a submarine.

At a typical diving depth of 800 feet, the water pressure is 350 psi. Low-pressure exhaust gas produced by conventional internal combustion engines can't be released into this pressurized seawater. But the Stirling combustion chamber operates with high pressure—around 435 psi. Thus exhaust can be expelled in deep seas.

The engine also has the advantage of being nearly vibrationless. It has pistons and a crankshaft; but because external combustion is continuous, there are no explosions. This adds a stealth benefit that could be impor-

tant for some submarine operations.

Sub Power AB—a Swedish company jointly formed by United Stirling and Kockums, a major shipbuilder—designed *Saga I*'s engines to burn diesel fuel. But what about the air needed for combustion? Hans Melbing, a project engineer at United Stirling, said the sub carries liquid oxygen at a temperature of -196 degrees C. The frigid liquid is the secret of *Saga I*'s endurance. "It's far more concentrated than compressed air," Melbing told me.

"To feed the engine we first vaporize the oxygen and store it in pressure cylinders," he explained. "But burning diesel oil in pure oxygen gives a flame temperature of 4,000 degrees C, which would melt even the special metals of the Stirling combustion chamber. Our answer to that is exhaust-gas recirculation."

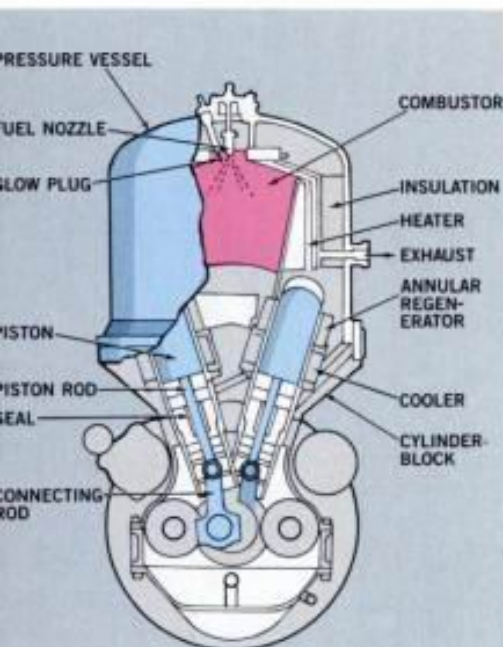
Melbing and his colleagues found that by adding four parts of exhaust gas to one part of oxygen they could create a mixture with the chemical composition of air. Diesel fuel burns in this mixture at 2,000 degrees C, which is normal for the Stirling.

Improved hull

Saga I is based on a pressure hull built 20 years ago by Capt. Jacques Cousteau for his *Argyronete* submersible. That project was too ambitious for its time, but the hardware was preserved, and Comex has updated it. Kept at atmospheric pressure, the hull holds a six-man support crew.

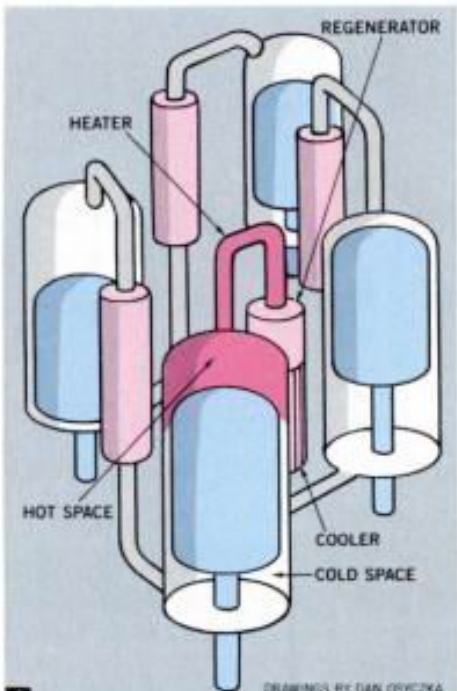
In a smaller habitat in the stern, with bunks for up to six divers, air pressure is equal to outside water pressure. "This eliminates both the risk of the bends, caused by sudden exposure to atmospheric pressure, and the lengthy wait in a decompression chamber," explains Didier Souzade, a senior marine engineer at Comex. "A simple air-to-water lock gives the divers fast access to the sea."

Comex recently joined two Canadian firms to form International Submarine Transport Systems. They plan to build more Stirling-powered subs for commercial exploitation of the ocean's riches. Says Souzade, "They could do for the oceans what the space shuttle is doing for space."



3

chamber, and the bottom sections are chilled by coolers. Between are regenerators that store heat as gas passes from hot to cold spaces and release heat on the return trip. The cylinders work in pairs: Heated helium expands and drives a piston down, compressing gas into the water-jacketed cold space. Most of the helium is forced



4

through the cooler, regenerator, and heater. The reheated gas is rammed at high pressure into the hot top space of the adjacent cylinder, where it expands to drive a second piston down. When the second piston rises, it returns the gas to its partner's cold space, and the cycle begins anew. In this engine there are four such independent cycles.

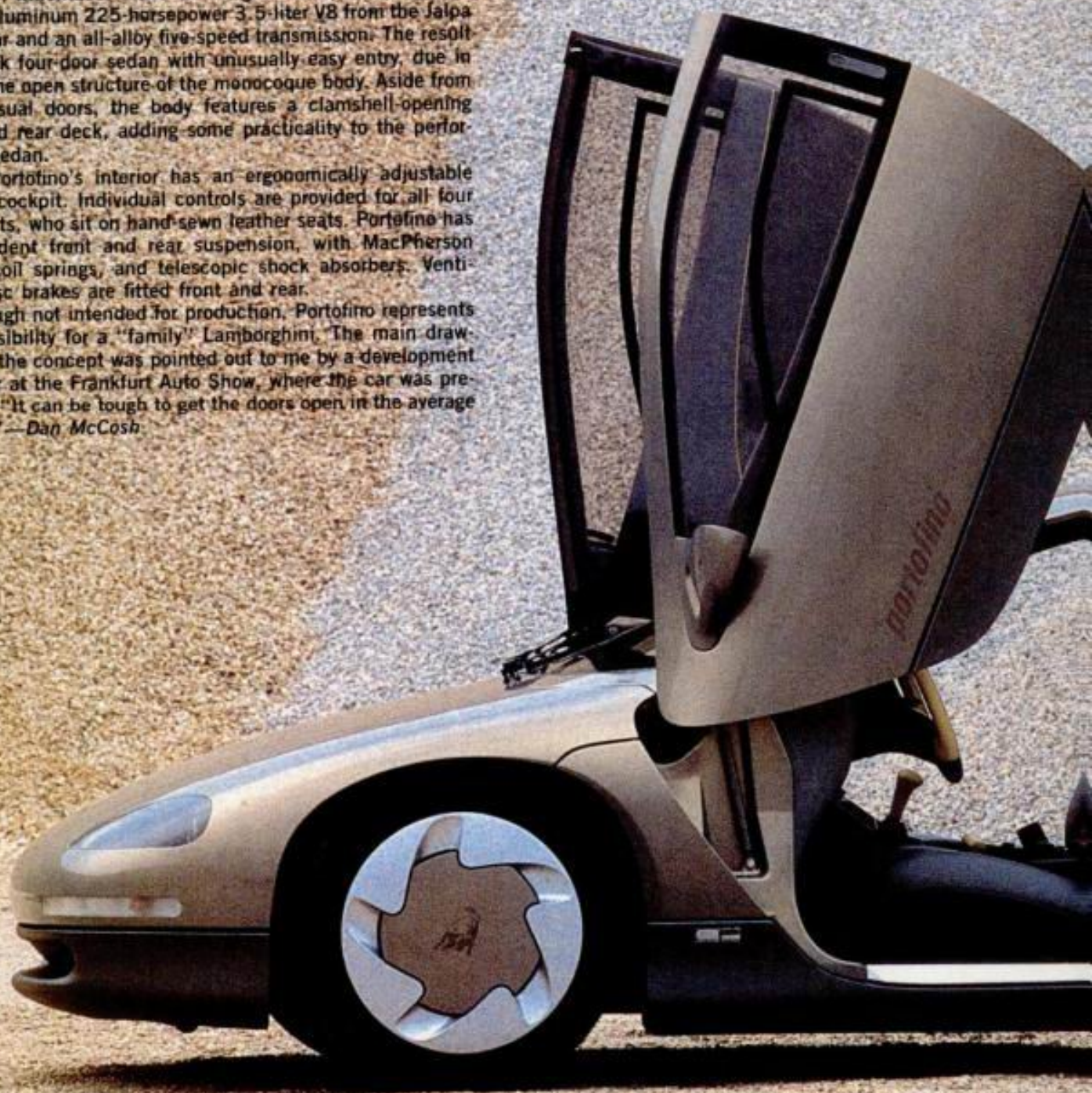
AEROSSEDAN

FRANKFURT, WEST GERMANY

How might a family sedan appear if it was designed, say, for a top speed of 150 miles per hour? The question is something more than theoretical for Chrysler Corp., which recently bought out Lamborghini, the Italian car maker famous for its exotic 200-mph sports cars. Now Chrysler has unveiled this cleaver-doored concept car called the Portofino, which uses some Lamborghini components including the aluminum 225-horsepower 3.5-liter V8 from the Jalpa sports car and an all-alloy five-speed transmission. The result is a sleek four-door sedan with unusually easy entry, due in part to the open structure of the monocoque body. Aside from the unusual doors, the body features a clamshell-opening hood and rear deck, adding some practicality to the performance sedan.

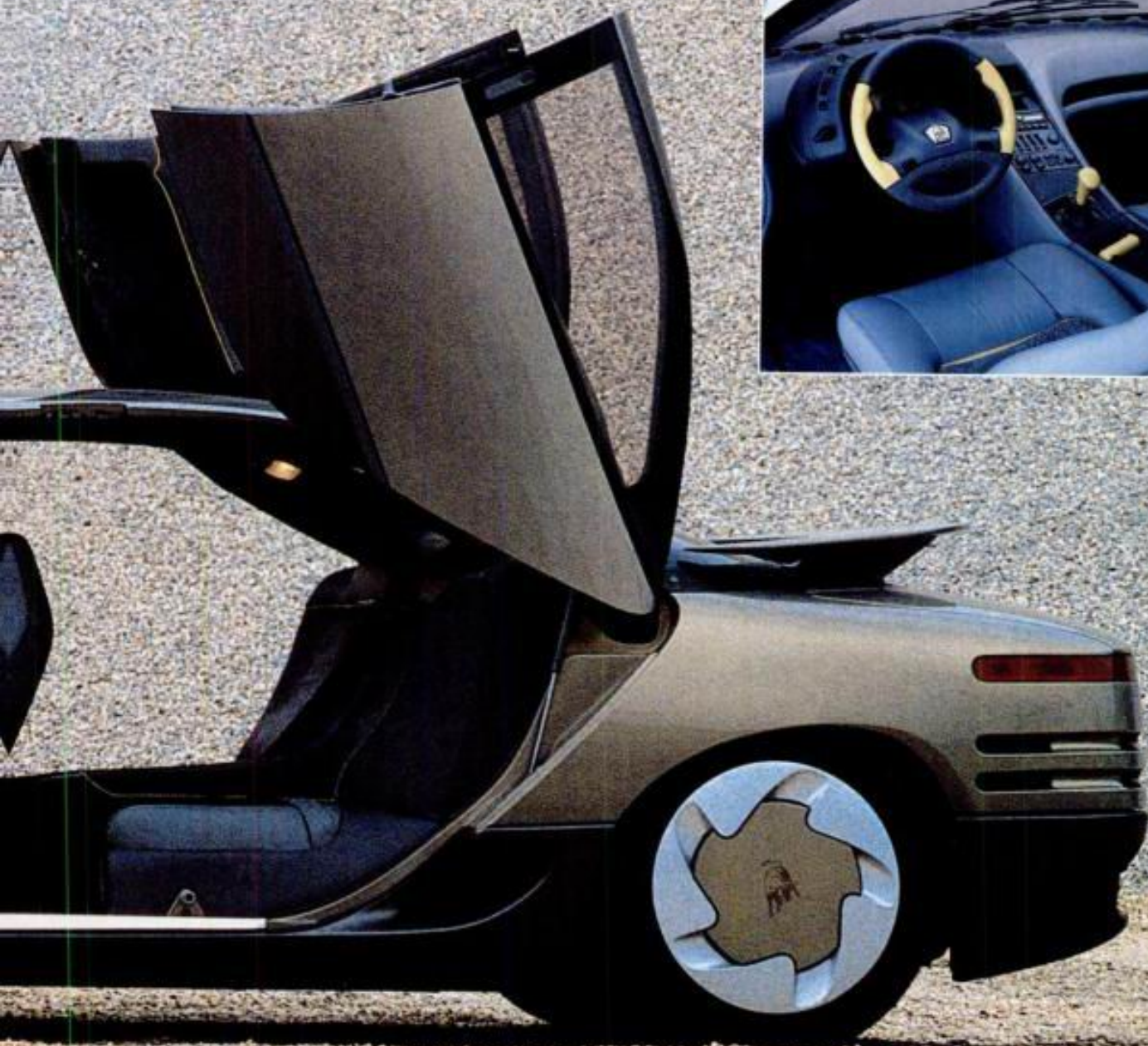
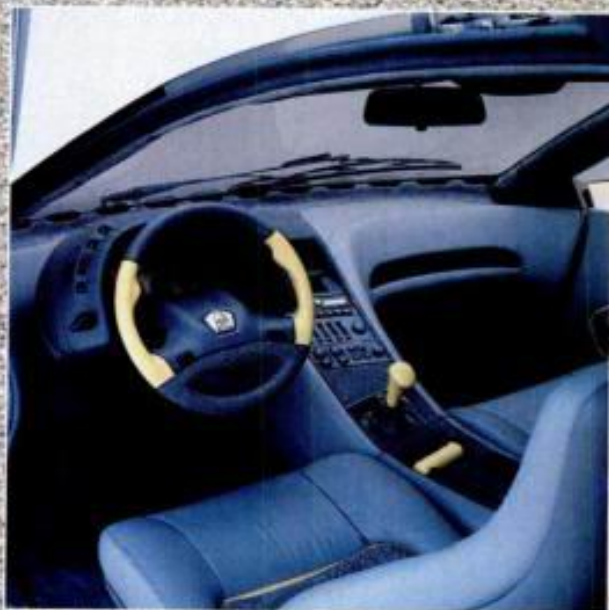
The Portofino's interior has an ergonomically adjustable driver's cockpit. Individual controls are provided for all four occupants, who sit on hand-sewn leather seats. Portofino has independent front and rear suspension, with MacPherson struts, coil springs, and telescopic shock absorbers. Ventilated disc brakes are fitted front and rear.

Although not intended for production, Portofino represents one possibility for a "family" Lamborghini. The main drawback to the concept was pointed out to me by a development engineer at the Frankfurt Auto Show, where the car was previewed: "It can be tough to get the doors open in the average garage." —*Dan McCosh*





Sleek Portofino features well-integrated headlights and flush glass (left). Interior has wraparound instrument cluster (below). Concept car's "rotational" doors swing up wide for easy access (bottom).



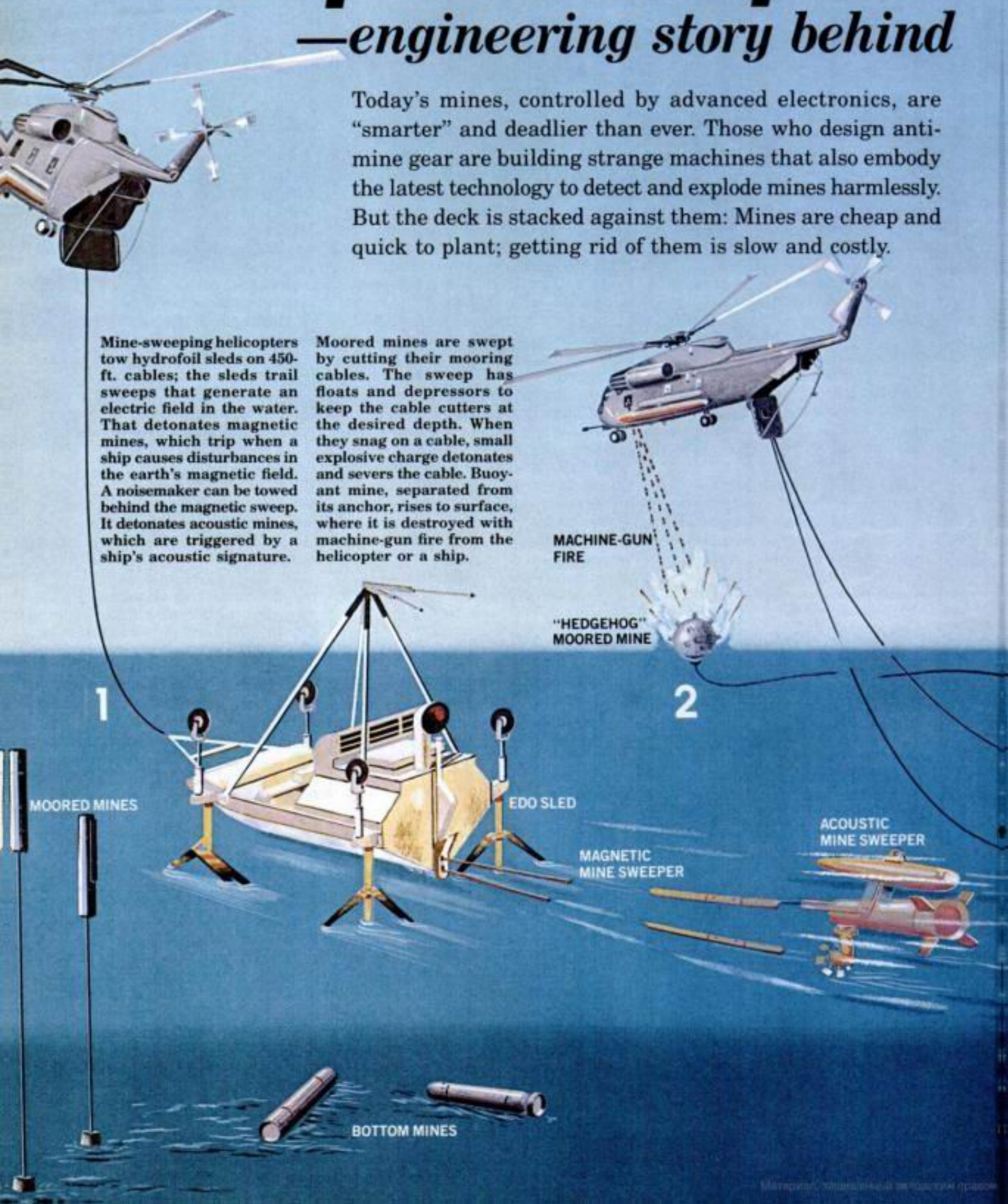
Super sweepers

—engineering story behind

Today's mines, controlled by advanced electronics, are "smarter" and deadlier than ever. Those who design anti-mine gear are building strange machines that also embody the latest technology to detect and explode mines harmlessly. But the deck is stacked against them: Mines are cheap and quick to plant; getting rid of them is slow and costly.

Mine-sweeping helicopters tow hydrofoil sleds on 450-ft. cables; the sleds trail sweeps that generate an electric field in the water. That detonates magnetic mines, which trip when a ship causes disturbances in the earth's magnetic field. A noisemaker can be towed behind the magnetic sweep. It detonates acoustic mines, which are triggered by a ship's acoustic signature.

Moored mines are swept by cutting their mooring cables. The sweep has floats and depressors to keep the cable cutters at the desired depth. When they snag on a cable, small explosive charge detonates and severs the cable. Buoyant mine, separated from its anchor, rises to surface, where it is destroyed with machine-gun fire from the helicopter or a ship.



vs. smart mines

the secret war

By BEN KOCIVAR, V. ELAINE SMAY,
and RICHARD LAYNE

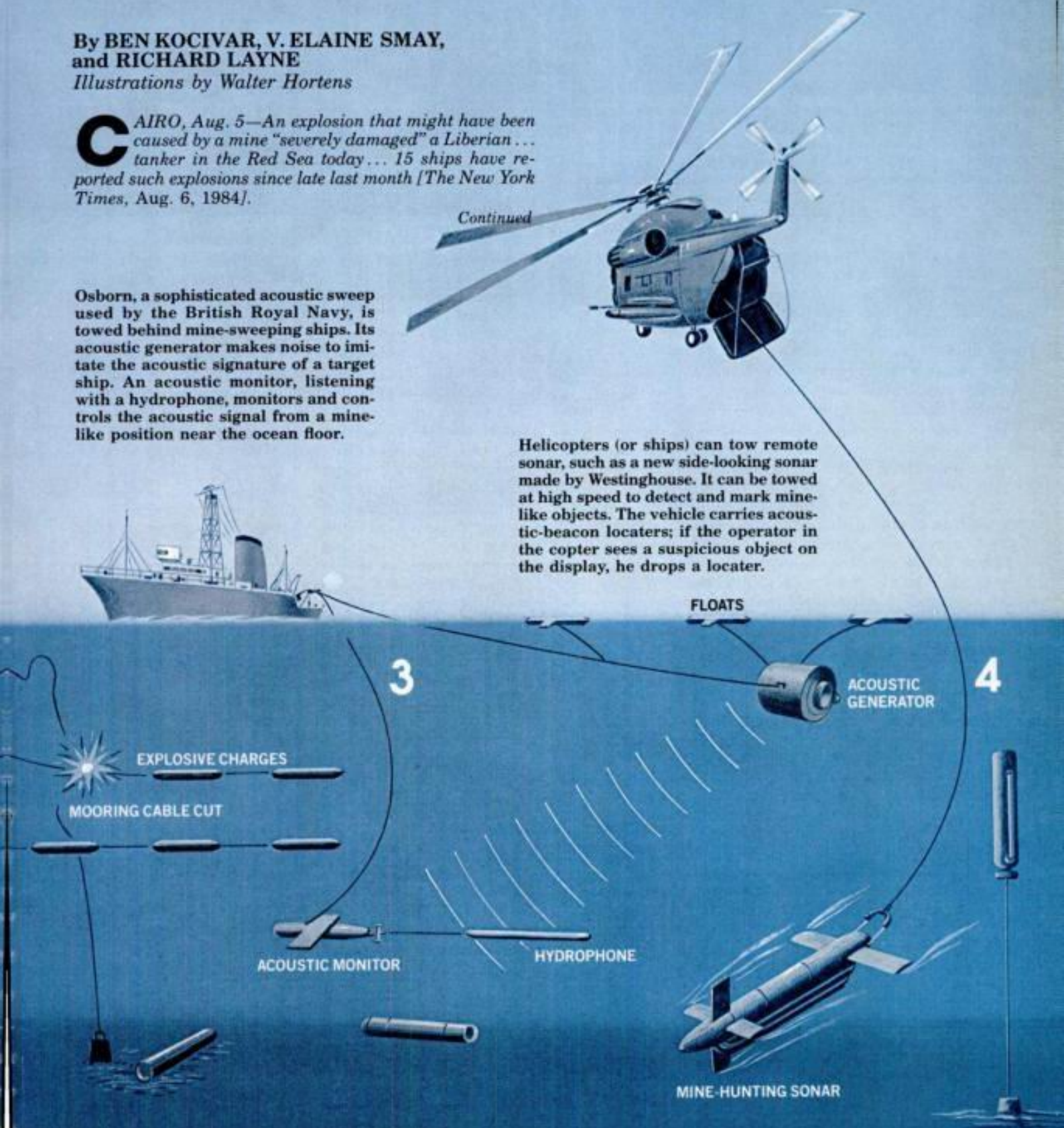
Illustrations by Walter Hortens

CAIRO, Aug. 5—An explosion that might have been caused by a mine "severely damaged" a Liberian ... tanker in the Red Sea today ... 15 ships have reported such explosions since late last month [The New York Times, Aug. 6, 1984].

Continued

Osborn, a sophisticated acoustic sweep used by the British Royal Navy, is towed behind mine-sweeping ships. Its acoustic generator makes noise to imitate the acoustic signature of a target ship. An acoustic monitor, listening with a hydrophone, monitors and controls the acoustic signal from a mine-like position near the ocean floor.

Helicopters (or ships) can tow remote sonar, such as a new side-looking sonar made by Westinghouse. It can be towed at high speed to detect and mark mine-like objects. The vehicle carries acoustic-beacon locators; if the operator in the copter sees a suspicious object on the display, he drops a locator.



mine explodes, the ship is out of range. But it doesn't always go according to theory. During the Korean War, when U.N. troops were preparing a landing at Wonsan Harbor, four U.S. mine sweepers were lost to mines.

Since the Vietnam era, the U.S. has relied mostly on helicopters to tow mine-sweeping gear. Flying over mined water is safer than riding on it. "And you risk losing an \$18 million helicopter and seven men versus a \$100 million ship and 70 men," said Emshwiller.

Speed of deployment is another advantage. Helicopters and the gear they tow can be quickly flown anywhere in the world in giant jet transports, as they were last August.

Both helicopters and ships can sweep for moored mines with gear that cuts the mine's mooring cable (see opening scenario). But to sweep for bottom mines they must tow gear that can mimic the relevant emanations of a ship so that the firing mechanism will detonate the mine.

The strange-looking hydrofoil sled on the cover allows helicopters to sweep for magnetic mines. The sled trails two electrode cables in the water, one long, the other short. An electrical current generated on the sled travels between the electrodes. That creates an electric field in the water that causes the same kind of perturbations in the earth's magnetic field that a moving ship creates. And that can set off a magnetic mine.

"Depending on the salinity of the water and other factors," said Emshwiller, "the magnetic field can be very large or relatively small." Generating a powerful enough field takes a lot of energy. So the sled carries a large engine and generator—far heavier than could be carried aboard a helicopter.

To learn about mine-sweeping sleds, one of our team (Ben Kocivar) visited EDO Corp. in College Point, N.Y., where they're made. There, he got firsthand evidence of

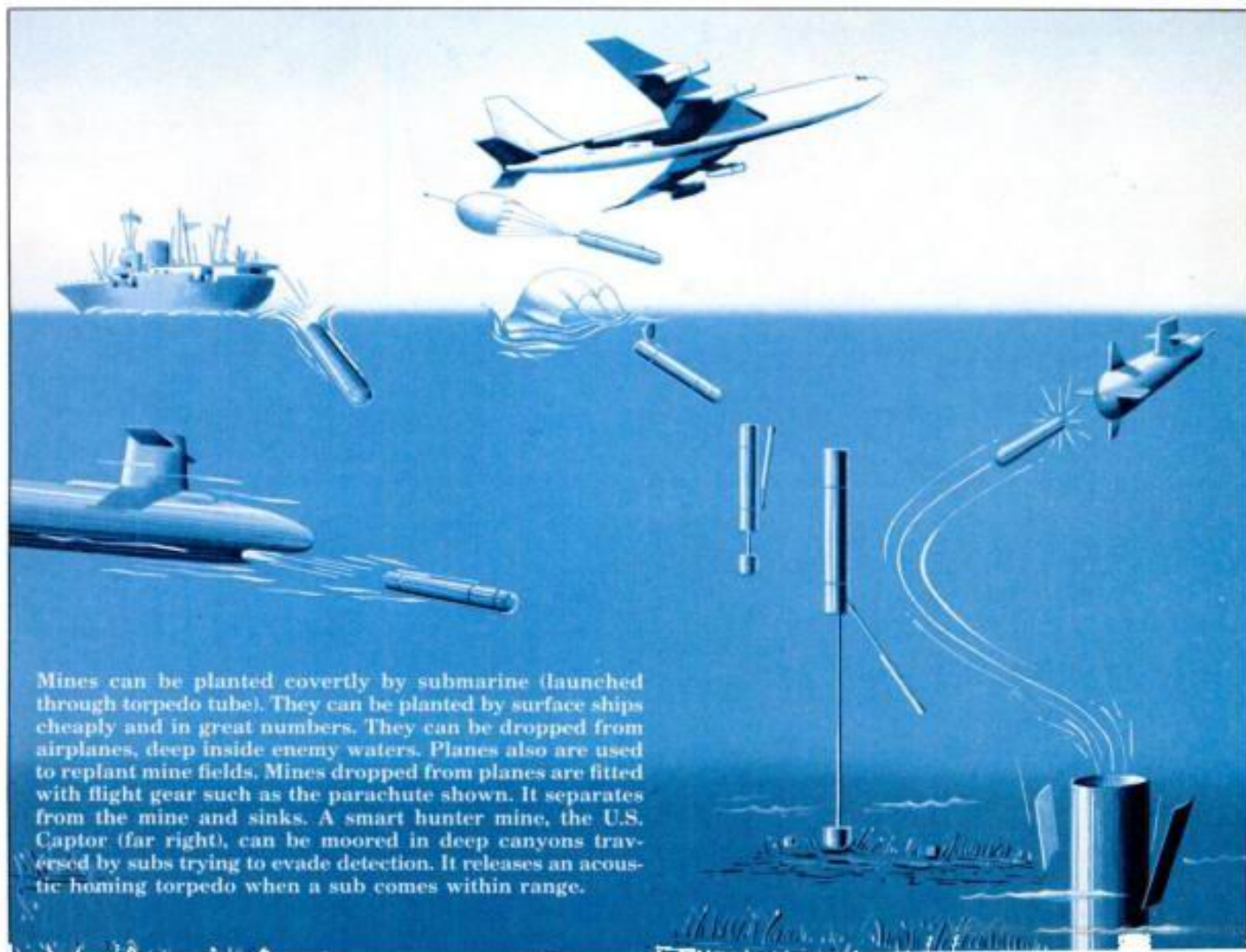
the secrecy surrounding the field. He reports: "The morning I visited EDO's warehouse-like plant, two model MK 105 sleds—predecessors of the AN/ALQ 166 pictured on the cover—were in for refurbishing. I aimed my camera at one, but before I got off a shot the EDO crew started shouting. It seems the cover for the sled's electronics had been removed. They snapped it back in place.

"The MK 105 sleds I saw are hydrofoils, like the new AN/ALQ 166, but the 105 has catamaran hulls instead of the monohull construction of the new model. The advantage of the new design: It can carry a heavier load—more fuel for the 1,200-horsepower Avco Lycoming engine, which is about three times as powerful as the one carried by a 105. The larger engine drives a higher-output generator and enables the magnetic sweeping gear to sweep a broader path and detonate mines in deeper water. The bigger, heavier 166 was designed to be towed by a new, more powerful helicopter called the MH-53E Super Stallion."

The EDO sleds are unmanned. The sweep operator, at a control console in the helicopter, can start and stop the turbine and raise and lower the hydrofoils. He can also control the output signals that create the magnetic field. It can be constant, or it can be pulsed so that its rate of buildup and decay mimic the signature of the mine's target ship. "You hope you have some intelligence on what kinds of ships the mine was after," explained the Pentagon expert. "If you don't, the first couple of sweepers will try one thing and the next couple will do something else."

The foil-borne sleds have a better chance of survival when they detonate a mine than would a craft that rode in the water. "You can blow up a mine very near one, and all it does is move it about a bit," said EDO's manager of advanced planning, Anthony La Marco.

(Continued on page 86)



Mines can be planted covertly by submarine (launched through torpedo tube). They can be planted by surface ships cheaply and in great numbers. They can be dropped from airplanes, deep inside enemy waters. Planes also are used to replant mine fields. Mines dropped from planes are fitted with flight gear such as the parachute shown. It separates from the mine and sinks. A smart hunter mine, the U.S. Captor (far right), can be moored in deep canyons traversed by subs trying to evade detection. It releases an acoustic homing torpedo when a sub comes within range.

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Coming: Aircraft that
use half as much fuel
By Wernher von Braun

THE '77 CARS

Close-ups of the new
models from
Ford and Chrysler

Nutcracker VTOL

folds in flight

HEAT PUMPS

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HOME
IMPROVEMENT

- Basement remodeling
- All about plastic laminates for counter tops
- Home insulation
- Dry-mix cement know-how
- Shaker utility room



Nutcracker VTOL

folds in flight



Hinged design of Grumman Nutcracker would enable jet to take off and land vertically, like a helicopter with the fuselage bent; or with a short (400-foot) deck run, with the fuselage straight. For a surveillance flight, 12-ton plane could loiter

New designs for Navy vertical-takeoff-and-landing jets give promise of spinoffs for civilians

By BEN KOCIVAR

BETHPAGE, L.I., N.Y. Imagine a plane in flight. As it slows to less than 120 knots, the rear half of the fuselage, complete with two big turbofan engines and a twin-finned tail assembly, starts to pivot down. The forward fuselage section and the wing remain level. The rear section keeps coming down until it is pointed straight at the ground. The plane is now hovering, sitting on its tail in the air, supported only by the powerful jet exhaust.

I recently "flew" the simulator for this way-out design at the Grumman Aerospace Corp. in Bethpage, N.Y. I also saw two radio-controlled flying models, each with a seven-foot wingspan. One did aerobatic maneuvers with the fuselage straight back. The other, with the fuselage bent as in the picture (right), hovered in an indoor hangar and inched forward, back, and from side to side.

This strange design, conceived by Grumman engineer Bob Kress and developed by a company team, is one of several the U.S. Navy is considering as part of an exotic new family of fighter and transport aircraft that will have both vertical- and short-takeoff-and-landing abilities. (Grumman stresses the VTOL—vertical takeoff and landing—capability of its new design,

but the Nutcracker will also have V/STOL capabilities.) Such planes would be able to fly from small ships such as merchant vessels or destroyer escorts and possibly from new mini aircraft carriers. They could provide air cover and anti-sub protection, and perform supply missions that cannot be accomplished by our limited number of nuclear carriers and land-based aircraft.

Not all potential applications are military. These same designs promise new ability to supply men and equipment to big offshore oil rigs and other deep-ocean installations. Big helicopters and fast surface ships do this work now, but they're not the ideal answer—ships are too slow and copters don't have the range. The approach might even lead to a new kind of airliner, but that—if it ever happens—is in the future.

A gleam in the eye

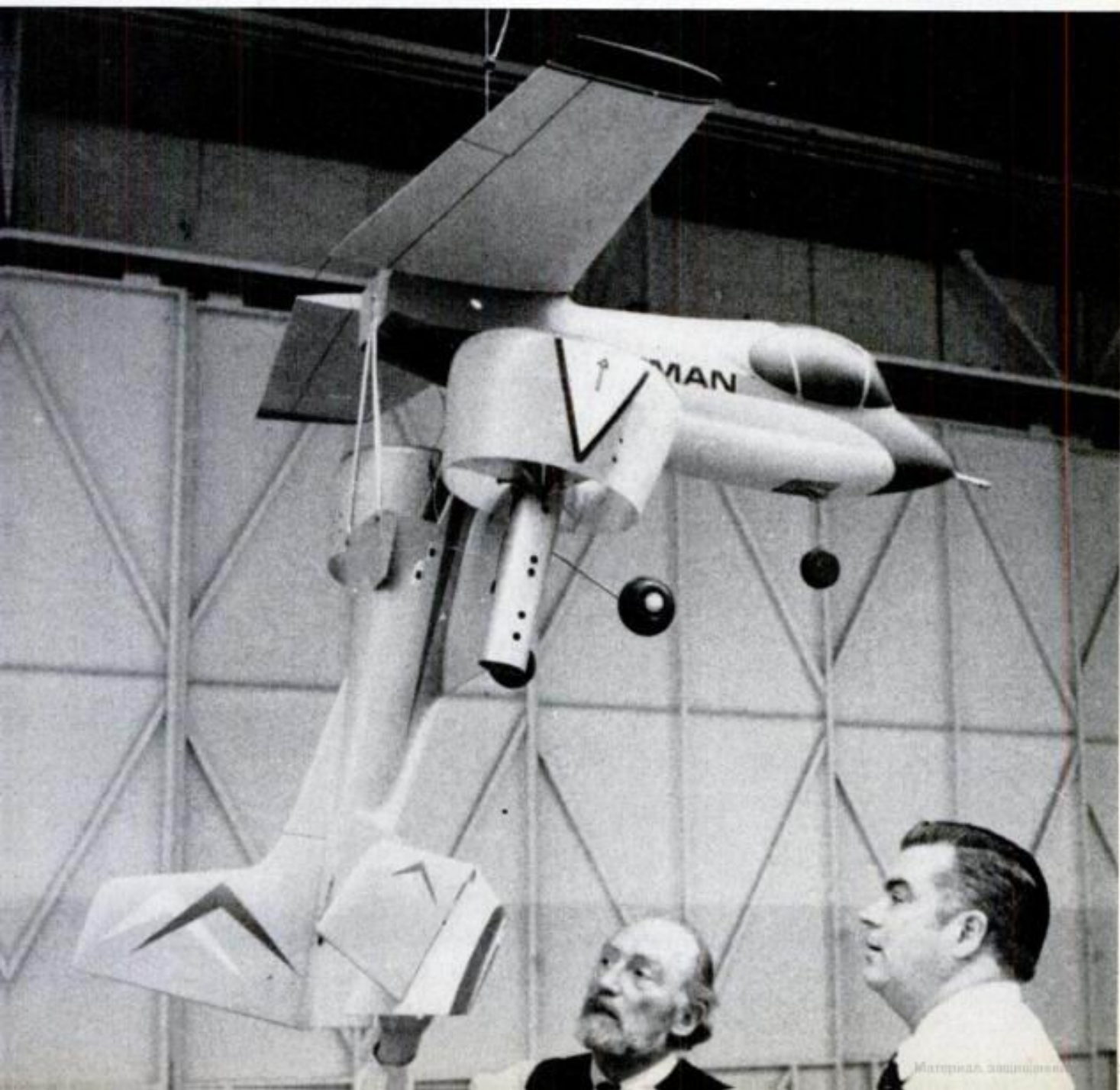
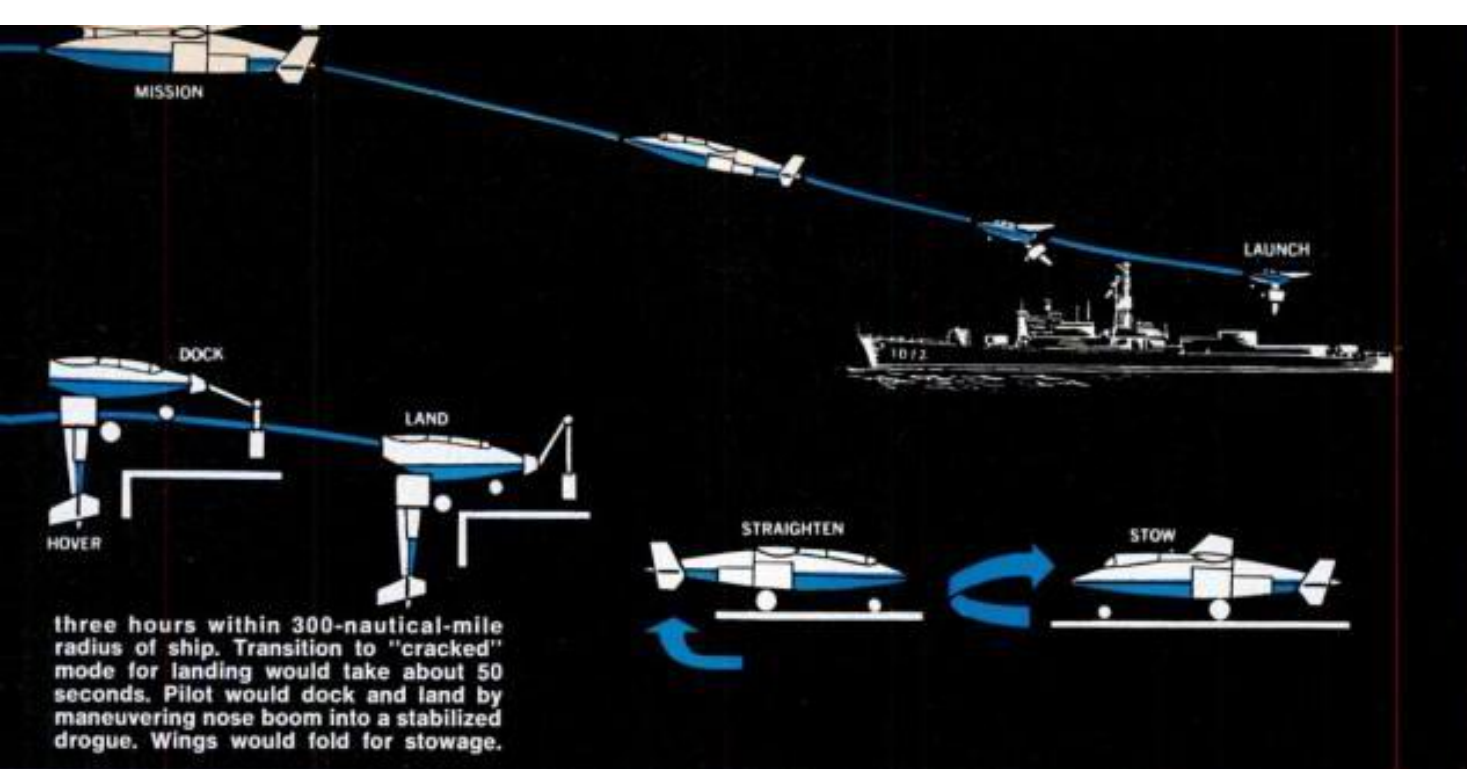
Despite the enthusiasm for the new design shown by Grumman engineers, it's well to remember that the concept is little more than a gleam in the eye at this point. All kinds of exotic V/STOL craft

Continued



TV screen in the cockpit of a Nutcracker simulator displays view pilot would see approaching a destroyer heaving in the waves. Manipulating a hand control in the simulator "flies" Nutcracker in for landing, diagrammed above. Despite rolling, circular docking drogue remains fixed above water.

Tail surfaces of radio-controlled Nutcracker model, which combine elevator, rudder, and aileron functions, are inspected by author Kocivar (right).



A Concorde is shown in flight, angled upwards from the bottom left towards the right. The aircraft is white with a red and blue stripe along the side. The background is a bright blue sky filled with soft, white clouds. The title 'THE NEXT SST' is prominently displayed in the upper half of the image. 'THE NEXT' is in a bold, black, sans-serif font. 'SST' is in a very large, blue, stylized font with a thick yellow outline, making it stand out against the sky.

THE NEXT SST

It's been 22 years since the Concorde, the world's first commercial supersonic airliner, roared off into the stratosphere. But the rare and beautiful bird has come to be viewed as a fuel-guzzling, noisy, cramped financial boondoggle and an environmental hazard. What were only suspicions during its development are now certainties. Jet exhaust at high altitudes may prove every bit as damaging to the fragile ozone layer as chlorinated fluorocarbons (CFCs).

Against this backdrop, airplane builders and jet engine manufacturers around the world face the daunting challenge of developing the next generation of SST. This time there must be no compromise of fuel-efficiency or pollution control.

There are two schools of thought on what form the next SST



ILLUSTRATIONS BY KERRY LESUE



Radical as it seems, nothing's missing from the oblique flying wing (left), proponents say; it's got everything needed to be the most efficient SST possible. But it's the conventional-looking delta-winged concept plane (above) that represents mainstream thinking.

WHO REALLY INVENTED THE MICROPROCESSOR?
IRAQ'S LETHAL WEAPONS • CONCRETE THAT BENDS

Popular Science

**NEW SOLAR
CELLS WIN IN
AUSTRALIA**



**OBLIQUE
WING:
FUTURE
SUPERSONIC
AIRLINER?**



SST

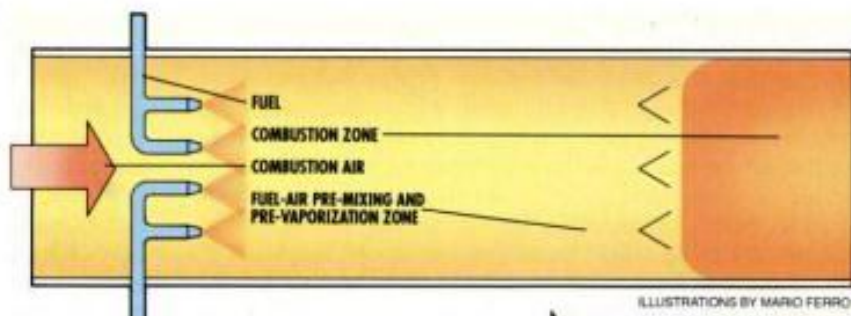
FORM FOLLOWS FUNCTION

The three jetliners superimposed below are a Boeing 747-400, which can carry more than 400 passengers, the 103-passenger Concorde, and a 250-passenger SST concept proposed by Boeing designers. Like the Concorde's needle-sharp form, the Boeing SST's great length and narrow wasp-waisted fuselage are necessary to keep aerodynamic drag acceptably low as the craft accelerates through the sound barrier. The airflow at subsonic speeds is relatively indifferent to an airplane's width, permitting the 747's designers to give this next-generation SST wide-body seating room for nearly its full length.

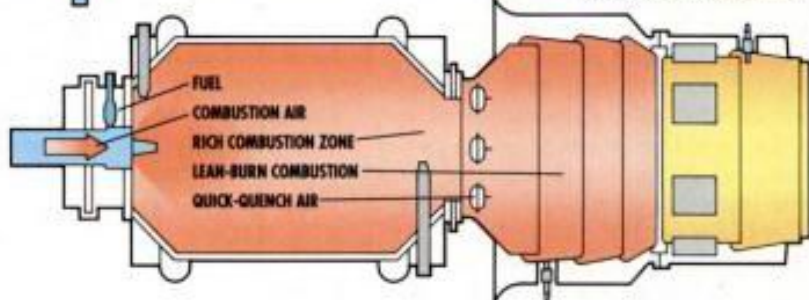
BOEING 747-400
LENGTH: 232 FT.
SPAN: 212 FT.

CONCORDE
LENGTH: 204 FT.
SPAN: 84 FT.

BOEING SST CONCEPT
LENGTH: 311 FT.
SPAN: 120 FT.



ILLUSTRATIONS BY MARIO FERRO



HIGH TECH, LOW NO_x

NASA Lewis is exploring jet-engine combustors that may help reduce nitrogen oxide emissions. The lean pre-mixed, pre-vaporized method (top) mixes the kerosene fuel with large quantities of air before it is burned further downstream. The rich-burn/quick-quench/lean-burn design (above) burns fuel in two stages, first using little air, then an abundance of it.

working on further defining what's safe for the atmosphere.

Tucked in a corner of a nondescript building on the far side of Cleveland's Hopkins International Airport is NASA's "high-pressure and temperature square-wave flame tube" designed to probe secrets of combustion. The heart of the rig—wired up to sensors and computers—is a chamber the size of a thick dictionary. During

the next 18 months, video cameras will peer through transparent quartz windows, and lasers and spectrometers will be trained at the fiery cavity and its exhaust outlet as combustion and emissions experts strive to devise a way of combining kerosene and oxygen, as all jet engines do, while producing a minimum of NO_x as a byproduct.

In an optimal oxidation process everything burns—every molecule of fuel combines with the right number of air molecules. "Lo and behold, when we have the perfect mixture for combustion, we have the highest amount of NO_x," Niedzwiecki laments. How can scientists hope to inhibit NO_x emissions dramatically if they are the natural result of any combustion? "Essentially," Niedzwiecki concludes, "we want to operate as fuel-lean or as fuel-rich as possible." Niedzwiecki and his colleagues at NASA Lewis, and researchers around the nation, are focusing on three complex engine technologies that mix fuel with air at different stages and rates as they pass through the engine's combustors.

Lean pre-mixed/pre-vaporized combustion:

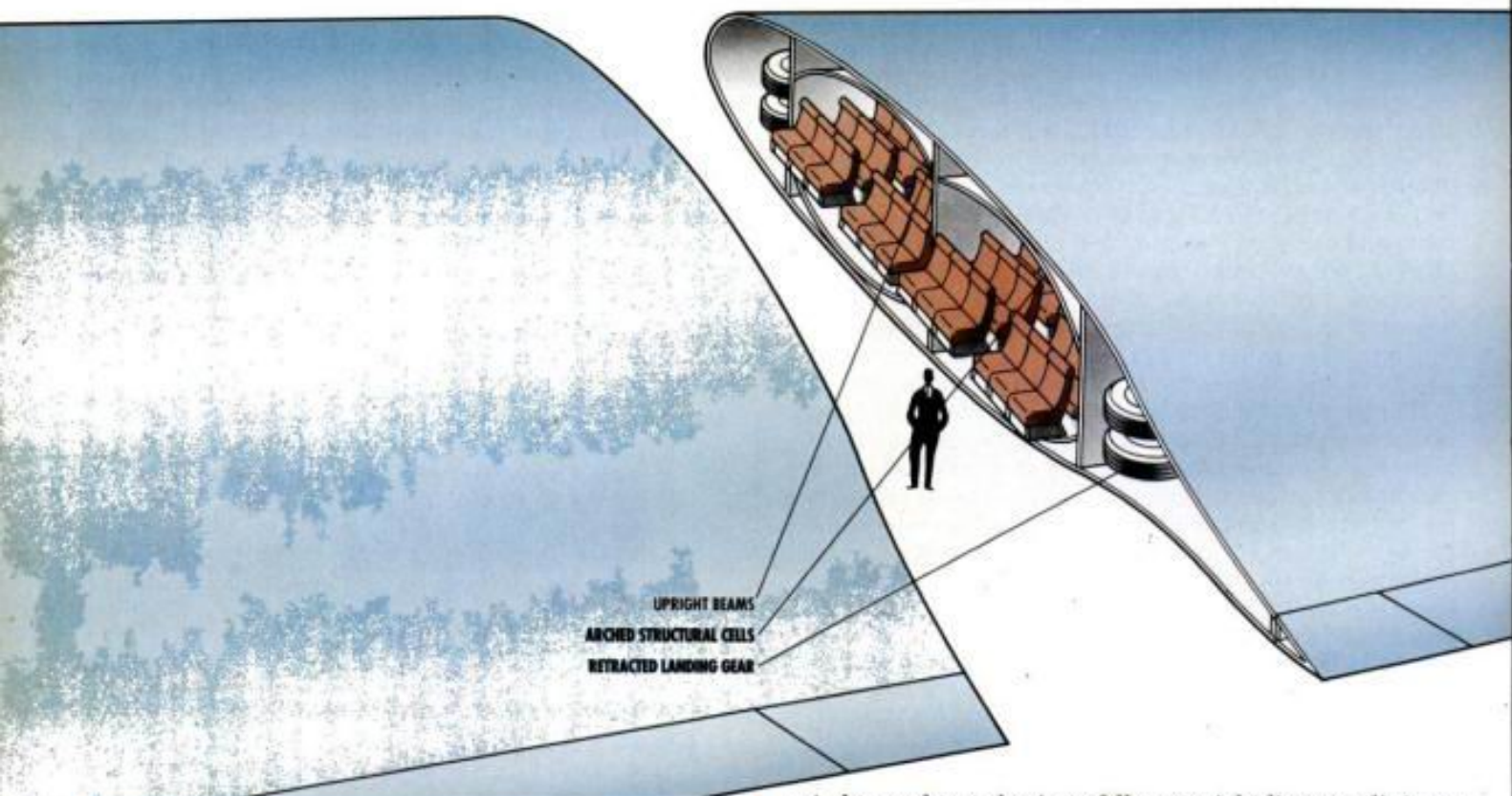
The challenge in this research is to optimize all the steps—air-to-fuel ratios, uniformity of the air-fuel mixture, speed of vaporization, and especially the speed at which the mixture flows through to the combustion zone—all of which occur in a few milliseconds. Standard jet-A kerosene is mixed with air upstream of the combustion zone, vaporizing it to a gas. Combustion takes place further downstream and is completed as quickly as possible.

Rich-burn/quick-quench/lean-burn combustion:

This would be a two-stage engine that controls NO_x by taking advantage of the low rate at which it forms in both

mine if advanced SSTs could be environmentally feasible and, if so, at what price. Airplane builders will be closely watching the space agency's progress. The scientists and engineers at NASA Lewis and other research centers are a long way from building an ultra-low-NO_x engine, to say nothing of flying it. But NASA does have a timetable for its SST research: The agency hopes that low-NO_x combustion under the conditions required for supersonic cruise can be demonstrated in laboratory test hardware by the end of 1991. If the theoretical methods prove out, then the next goal is to build real-world combustor hardware by the end of 1995 and install it in test engines. "The environment," says Niedzwiecki, "is not a negotiable item."

But that target is based on a working assumption about environmentally acceptable levels for NO_x; other scientists are



wind tunnel tests begin to follow straight lines, outlining a cone-shaped shock wave that has its tip at the plane's nose. If the Mach cone trailing back from the nose of an airplane flying supersonically cuts across its wing tips (see diagram opposite page), shock waves can batter the wings severely enough to cause them to disintegrate. The faster an airplane flies, the narrower its Mach cone, therefore the further back its wings ought to be swept, Jones concluded.

In addition, Jones's work showed that a swept wing had only one-tenth the drag of a straight wing at Mach 1. He went on to prescribe the delta wing for aircraft flying closer to Mach 2. Current swing-wing aircraft such as the F-14 fighter exploit these principles to obtain good lift from straight wings at takeoff and low drag from increasingly swept wings as the aircraft accelerates through the sound barrier.

Jones became interested in looking beyond delta wings after the 1947 discovery by aerodynamicists Wallace D. Hayes and Theodore von Karman at the California Institute of Technology that swept wings theoretically should have the same drag regardless of whether they are going forward or backward. This model, called the reversed-flow theorem, says Jones, meant that an arrow-shaped wing, traveling point foremost, couldn't be the single-best configuration because the same triangular shape traveling broad-base forward, according to the theorem, would have equal drag performance.

As a result, he approached the problem of discovering the *true* optimum wing configuration from the premise that the most efficient wing would look the same coming or going. His calculations led him to conclude that a single shape—the long, narrow ellipse—delivered the best lift-to-drag ratios from subsonic speeds all the way to Mach 2. The only modification necessary was to have it assume an oblique direction during flight above Mach 0.8. This would keep its leading edge behind the Mach wave trailing from its forward tip. Thus the oblique wing concept was born. Jones soon went on to discard the fuselage and tail altogether and concentrate on oblique flying wings.

Jones first tossed oblique flying wing models into a room full of people at the 1958 International Congress of Aero-



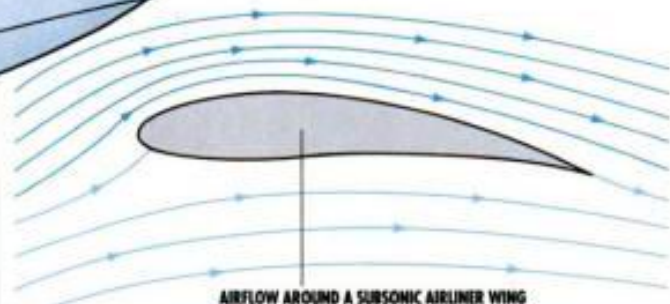
At his California home, aerodynamicist Robert T. Jones demonstrates the flight-worthiness of the oblique flying wing with a balsa-wood model.

Langley Medal for extensive contributions to theoretical aerodynamics, only began garnering the attention of people in the aeronautical world at the close of World War II, when it was discovered that the Germans had been testing theories on sweeping aircraft wings aft to achieve supersonic flight. Jones's presentation of similar calculations and wind tunnel test results in 1945, while working at the Langley Memorial Aeronautical Laboratory, were initially ignored. Nevertheless, his discoveries would revolutionize the configuration of aircraft.

In essence, he found that a dramatic change occurs in the airflow around a high-speed airplane as it thunders past the speed of sound. The streamlines seen in supersonic

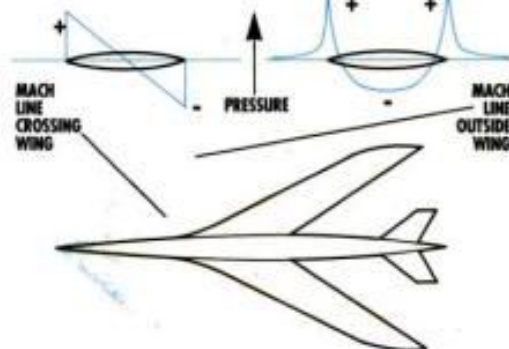
CHEATING THE SOUND BARRIER

When a subsonic airliner, such as the Boeing 747, flies at its cruising speed, the flow of air over its wings is smooth. Viewed in a wind tunnel, the streamlines surrounding a model of its wing trace soft, almost unperturbed curves.

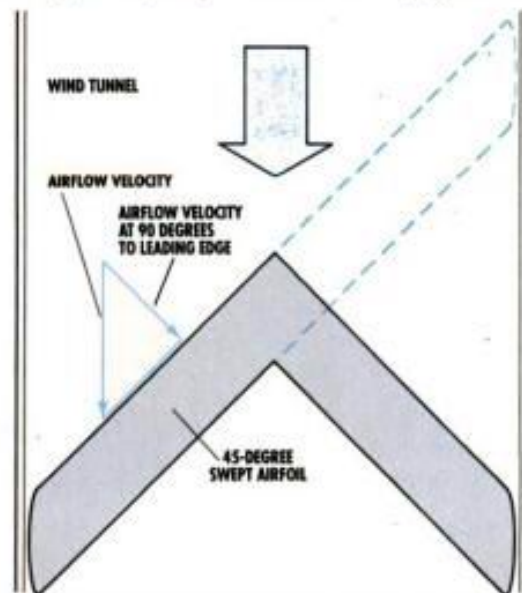


AIRFLOW AROUND A SUBSONIC AIRLINER WING

At supersonic speeds, Mach lines, or straight shock waves (below), angle back from an aircraft's nose. If the Mach line crosses the wing, an abrupt pressure rise occurs at the wing's leading edge, followed by a sharp pressure drop ending suddenly at the trailing edge. The result is a sonic boom and a roughly tenfold increase in drag. When the airplane's wing is swept behind the Mach line, however, positive pressures at the leading and trailing edges are balanced by negative pressure underneath it, minimizing drag.



Robert T. Jones explained this phenomenon in the 1940s when he showed through wind tunnel tests that a swept wing (below) actually responds to the lower velocity of the airflow that it experiences at right angles to its leading edge. Even though the wing's speed is supersonic, it behaves as if it were flying subsonically.



The 500 passengers in an oblique flying wing would face sideways to the airliner's direction of flight in rows of seats running from front to back of the craft. Lightweight arch-shaped structural cells with upright beams form the principal load-bearing members. Landing gear, baggage holds, fuel tanks, and various componentry are in the areas surrounding the passenger cabin.

nautical Sciences in Madrid. "I flew them at a cocktail party. The Russians were there, the head of NASA was there... Oh, it was fun," he recalls. "I gave a talk on supersonic wing design, and I explained the theory of the oblique ellipse, which I had developed in 1952."

At the next congress in 1962, Dietrich Kuchemann, the Concorde's chief designer, presented a paper on plans for the new airliner. Its narrow delta wing wouldn't have enough span to fly efficiently at low speeds, so the plane required a noisy afterburner assist to get off the ground. Hence, about 40 percent of its fuel load would be needed for takeoff, climb, and reserve. Godfrey Lee, a well-known engineer associated with the British Handley-Page Aircraft Co. who had been enthusiastic about the oblique wing models in 1952, pointed out that an oblique flying wing design might save enough fuel to double the Concorde's payload. "But at that time no experimental confirmation of the theory was available, so it's not surprising that such a concept was rejected," Jones recalls.

Funding for oblique wing research has had its ups and downs over the years, as will any project that challenges the current definition of how a good design should look. By conducting tests over the past 20 years, and by funding projects at Stanford University in Stanford, Calif., the NASA Ames Research Center in Mountain View, Calif., has played a central role in the oblique wing's history. Jones retired from NASA Ames in 1981 as principal engineer after a long and distinguished career.

The most visible outcome of the work at Ames is the AD-1 research aircraft, a low-speed lightweight jet designed by Burt Rutan under a NASA contract to explore the flight behavior and controllability of a pivoting oblique wing mounted atop a conventional fuselage. Testing proved the AD-1 to be a well-behaved and fuel-efficient plane. NASA pilot Tom McMurtry made demonstration passes at a recent Oshkosh air show with the wing yawed at its maximum angle of 60 degrees.

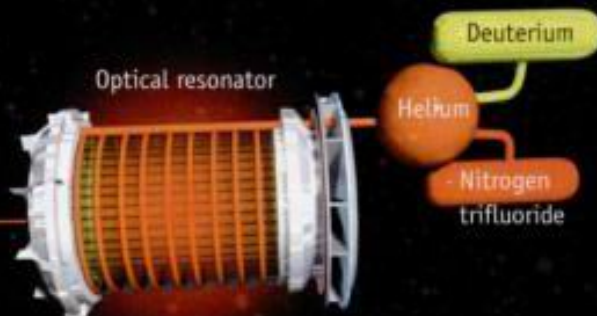
Real-world oblique-winged airplanes with conventional fuselages have also been the subject of two major studies, one of them conducted for NASA by Boeing in the 1970s. It

(Continued on page 90)

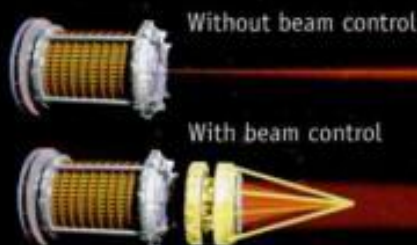
Return to STAR WARS

How the Space-Based Laser Works

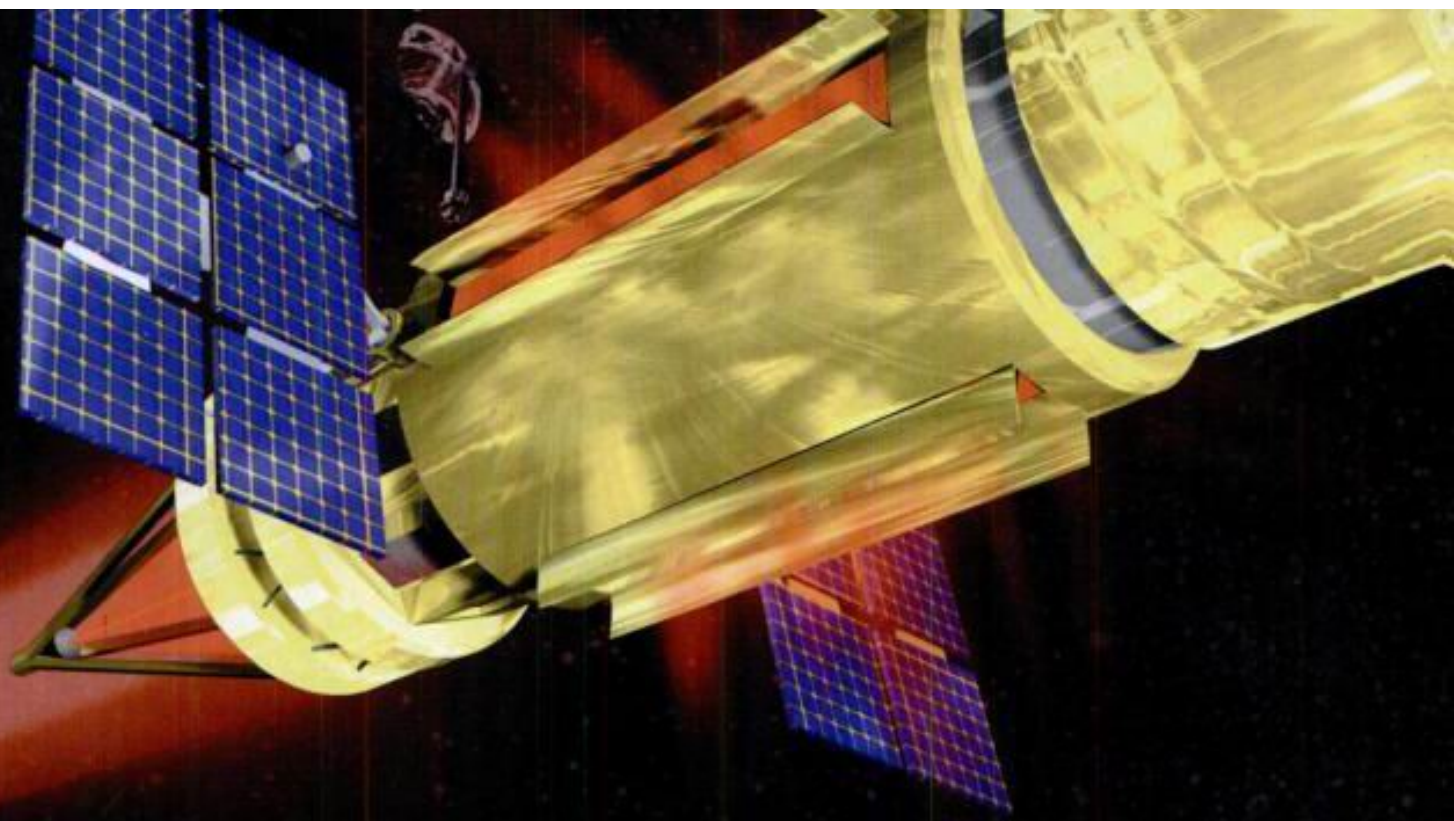
THE TWO KEY COMPONENTS of the space-based laser are the laser itself and the mirror/beam control assembly that targets missiles.



To generate a laser beam, deuterium, nitrogen trifluoride, and helium are mixed to produce fluorine, which is burned with hydrogen in a mirrored chamber called an optical resonator. This creates "excited" hydrogen fluoride molecules. As these excited molecules return to a rest state, they emit photons. An optical resonator amplifies this cascade of photons, transforming them into a laser beam.



This laser beam would quickly disperse well short of a target without the use of an optical assembly that includes special mirrors that enlarge and direct the beam to focus on a single point.



At the risk of violating international treaties, the U.S. military is developing space-based laser weapons as a defense against enemy missiles.

A MISSILE ARMED with toxic biological agents lifts off from a launch pad in North Korea. The missile, its launch timed to coincide with an invasion of neighboring South Korea, climbs into the atmosphere, its size and trajectory revealing to space-based sensors that the West Coast of the United States is the ultimate target.

By Frank Vizard

Suddenly, seemingly out of the thin air, a powerful laser beam hits the missile, disintegrating the warhead within seconds. The fearsome biological agents aboard the missile fall to Earth, spreading misery over the country that launched the attack.

The beam that destroyed the missile came from one of a constellation of orbiting satellites armed with lasers. This ring of fire is not only capable of detecting and shooting down enemy missiles, but someday may also be able to strike at ground targets. Space has now become a fourth battlefield—along with land, water, and air.

If this scenario sounds familiar, it should. During the cold war, President Ronald Reagan proposed such

a satellite system as the cornerstone of his Strategic Defense Initiative. Popularly known as Star Wars, the program's goal was to develop a space-based laser that could destroy 2,000 intercontinental ballistic missiles at a rate of 40 per second. Such a weapon proved impossible to build at the time, and President George Bush subsequently pronounced the Star Wars idea dead.

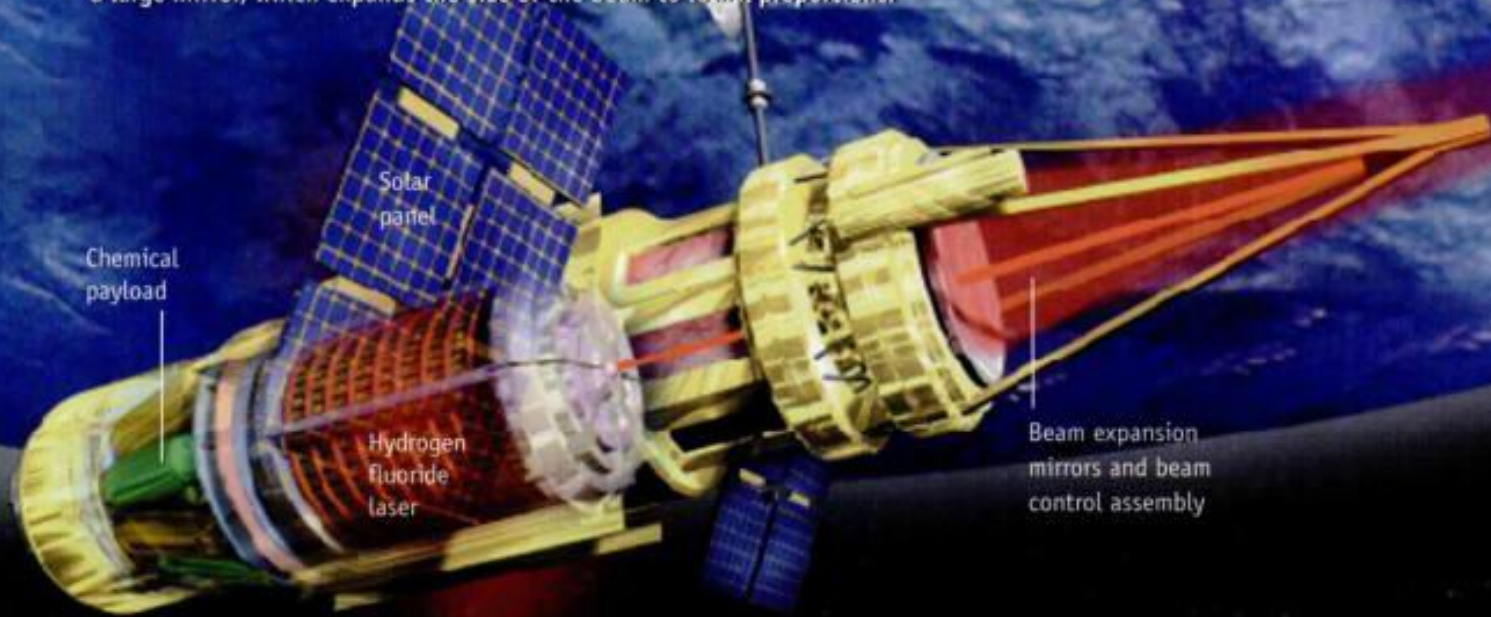
But the program never really went away. Although funding was reduced, the federal government continued to conduct research through the Ballistic Missile Defense Organization, the U.S. Space Command, and the U.S. Air Force. And this year, with \$168 million allocated for the development of a space-based laser, the United States is taking a significant step toward the use of weapons in space.

While space has long been a theater of military operations, these activities have been confined to communications, reconnaissance, and surveillance. Now, despite the absence of a national policy and at the risk of violating international treaties, the U.S. military is developing a satellite-borne laser weapon capable of destroying enemy missiles seconds after

ILLUSTRATIONS BY DON FOLEY

Firing the Space-Based Laser

THE HYDROGEN FLUORIDE laser emits a thin beam that is reflected onto a large mirror, which expands the size of the beam to lethal proportions.



launch. This weapon could be in orbit in five to 10 years—and maybe even sooner—depending upon how quickly the United States needs to respond to perceived hostile actions. And in recent months, the perception is that the threat is becoming greater.

"We are affirming that there is a threat, that the threat is growing, and that we expect it will pose a danger not only to our troops overseas but also to Americans here at home," said Defense Secretary William S. Cohen at a January news conference regarding missile attacks from rogue nations.

Many U.S. military strategists view the current period in history as a strategic pause, a between-wars rest break during which our armed forces should be gathering strength. This pause, they say, offers an opportunity for the United States to seize control of a new frontier: space. That idea also appeals to many corporate executives in the space industry, who are pressing the military to provide protection for their commercial satellite assets, just as the Navy is expected to protect U.S. merchant ships.

The space-based laser isn't the only weapon being considered for deployment in space. According to the Space

Command's long range plan, published last spring, potential space weapons systems also include high-power microwaves to destroy enemy communications and information systems, and a military spaceplane that could arrive over potential trouble spots within 90 minutes of launch. These weapons would be supported by new detection satellites such as the Space-Based Infrared System, a network of orbiting sensors able to detect objects as small as 3 feet in size.

But the core weapons system—the one furthest along technically and the one most likely to be deployed first—is the space-based laser, or SBL. "SBL's impact would be revolutionary," says William Martel, director of the Air Force's War College in Montgomery, Alabama. "It would make it nearly impossible for anyone to use ballistic missiles against the United States." From a tactical standpoint, SBL is as significant as the blitzkrieg methods of German tanks in World War II, or the advent of carrier-based naval warfare.

As conceptualized by the Air Force, a constellation of 20 laser-firing satellites would orbit about 800 miles above Earth. While the laser's exact power is classified, imagine a weapon that can

destroy an enemy missile as many as 2,500 miles away in less than 10 seconds. And if multiple missiles are launched, the laser can shift from one target to another in less than a second. Each SBL would have a total lasing time of between 200 and 500 seconds, enough to destroy about 100 enemy missiles.

At the heart of this weapon is a hydrogen fluoride chemical laser that mixes nitrogen trifluoride, deuterium, helium, and hydrogen to generate a beam in the vacuum of space. If an SBL runs out of chemical ammo, it could be resupplied by a spaceplane or a remotely controlled space vehicle.

The main limitation to a hydrogen fluoride laser is that the beam cannot effectively penetrate the atmosphere below an altitude of about 10,000 feet, because water vapor absorbs too much of the light. While the weapon's range is sufficient to destroy an enemy missile during its boost stage, seconds after launch, it does prohibit the targeting of objects on the ground. However, this limitation could be overcome as new lasers are developed. One candidate is a modified hydrogen fluoride laser, called HF Overtone, that emits shorter-wavelength light for a more



Finding the Target

SURVEILLANCE SYSTEMS IN SPACE would be able to signal SBL of an enemy missile launch. Acquiring the target and firing upon the missile is a three-stage process that occurs in less than a second.



Sensors aboard the SBL note the trajectory of ballistic missiles launched by a hostile power. These missiles would still be in the boost stage.



The sensor picks out the plume of one missile and hands it over to a higher-resolution sensor that calculates the position of the missile body.



A laser illuminator then targets the missile body. A sensor tuned to the wavelength of the illuminator presents a picture of the targeted missile.

powerful beam. Work on such advanced lasers, which now generate only a few kilowatts of power, is still in its infancy.

Just how easy would it be to intercept a fast-moving missile from space? Military experts say it wouldn't be as tricky as other defensive systems that have been proposed, such as ground-based missiles designed to "hit a bullet with a bullet." The Pentagon has already spent about \$51 billion to develop a Theater High Altitude Air Defense, envisioned as an antiballistic missile umbrella for regional conflicts, but the system has failed to hit a single incoming missile in five attempts. By contrast, contractor estimates to the Senate Armed Services Committee predict that SBL development will cost only \$20 billion (although internal Air Force estimates use a figure closer to \$80 billion).

So far, the Air Force has awarded Boeing, Lockheed Martin, and TRW with SBL development contracts worth \$168 million. This represents the first serious funding since the demise of the Star Wars program. Assuming Congress approves more funding over the next few years, the Pentagon plans to build a half-scale \$1.5 billion SBL demonstrator that would be launched

sometime between 2005 and 2010. If missile threats from rogue nations like Iraq or well-heeled terrorists like Osama Bin Laden escalate in the months to come, SBL development could be accelerated. North Korea, for example, is known to be working on a ballistic missile with enough range to hit Alaska or Hawaii.

While a 20-satellite configuration is the ideal deployment scheme, other arrangements are also being considered, according to Lt. Col. Randy Weidenheimer, commander of the SBL project at the Los Angeles Air Force Base, a facility notable for its lack of a runway. One concept would deploy 10 satellites and an equal number of orbiting mirrors that would bounce laser beams to their targets. A third alternative would pair a ground-based laser with an array of orbiting mirrors. The problem with these alternatives is that they would require mirrors as large as 98 feet in diameter, which would be expensive to construct and difficult to fit into launch vehicles.

Regardless of which system is chosen, launch costs could be astronomical. Each laser-firing satellite will weigh about 77,000 pounds, more than three times the weight of the Hubble Space

Telescope. Currently, launch costs range as high as \$40,000 per pound. SBL developers hope to cut those costs in half with a next-generation rocket launcher, the Evolved Expendable Launch Vehicle. Two different versions of the vehicle are being developed by Boeing and Lockheed Martin.

SBL satellites are heavy because they require numerous components. Most of these components are surprisingly far along in their development, because much of the technology is being adapted from other programs. The laser itself is derived from the successful Airborne Laser (ABL) plane being built by the Air Force. Carried aboard a converted 747 jet, ABL is intended to shoot down tactical ballistic missiles, while SBL will have a longer range for global warfare. ABL and SBL both use chemical lasers, but ABL uses hydrogen peroxide and chlorine gas to produce "excited" oxygen molecules that are mixed with iodine. TRW, which is developing the lasers for both projects, also builds high-power lasers for the Army's High Energy Laser Systems Test Facility in New Mexico.

Another borrowed component of SBL is the mirror that focuses the beam on its target. Rather than create

21st Century SST

Forget the Concorde.
Future supersonic transports will fly faster *and* meet noise and pollution rules.

Faster Flights for Travelers

With a 5,700-mile range, the High Speed Civil Transport (HSCT) will bring supersonic travel to the Pacific—more than halving flight times.



	SUBSONIC (hr.)	HSCT (hr.)
TOKYO-LAX	10.3	4.3
TOKYO-HAWAII	7.0	2.8
SYDNEY-HAWAII	8.8	3.5
SYDNEY-LAX	14 (nonstop)	7.3 (1-hr. stop)

Fuel in the arrow wing

Floor angle changes along fuselage length

Seating six across

ILLUSTRATIONS BY BOB SAULS/JOHN FRASSANITO & ASSOCIATES

YOU'RE 10 HOURS into a flight out of Hong Kong. You've polished off some work on your laptop, read *Forbes* and

By **Bill Sweetman**

Fortune, and had your fill of the enter-

tainment available via headphone. You'd like to snooze but you're too keyed up.

Los Angeles is 8 hours away.

Welcome to hell. Now, let's talk about supersonic airliners—because if you were flying in one of those, you'd have been on the ground an hour ago.

Some critics have written off supersonic airliners as noisy, polluting, and uneconomical. But engineers at NASA, Boeing, General Electric, and Pratt & Whitney

are confident that it will be possible, in the next decade, to build a High Speed Civil Transport (HSCT). The HSCT they envision will carry 300 passengers from Los Angeles to Tokyo at Mach 2.4—1,600 mph, or three times as fast as today's jets can make the trip—reducing the flight time from 12 hours to under 5. The aircraft will meet the same noise rules as subsonic aircraft, and fares would be only 20 to 25 percent higher than today's.

The engineers' confidence is based on the results of a NASA-led program that started in 1990. General Electric program manager Leigh Koops



To keep costs down, the High Speed Civil Transport will carry some 300 passengers.

With synthetic vision, even fog or other bad weather can't ruin the view: Instead of windows, flat-panel displays provide computer-generated images and other information.

calls the project's progress extraordinary. "We're within a hair's breadth of goals that were considered almost unreachable," he adds.

Now NASA is planning the next stage of the project, including the design, construction, and ground-testing of a prototype for the transport's awesomely large engine and its noise-suppressing exhaust nozzle. This stage of the project could start next year, paving the way for the industry to launch a full-scale program in 2008 or '09. The aircraft could enter service in 2015.

There's a crucial difference between this project and the U.S. efforts to build a supersonic transport, or SST, in the 1960s (see "Supersonics: The Story So Far"): The U.S. government is not going to build the airplane. Instead, today's program aims to develop technology that

makes the HSCT a less risky proposition, so that industry can develop it with its own money and be reasonably sure that there will be no major technical snags.

As the project started, NASA and industry had reached a broad consensus on the limits of the airplane's size and performance. A large payload means low costs, and 300 passengers are about as many as the airplane can accommodate before it grows too large to fit into airports. The range is a trans-Pacific 5,700 miles. The speed is dictated by heat. The HSCT, which is heated by air friction at high speed, has a system of heat exchangers that cools the cabin and dumps the heat into the fuel. Mach 2.4 is as fast as an airplane can go before conventional jet fuel gets too hot and must be replaced by costly special blends.

Early program research focused on

two show-stopper issues. If the HSCT could not meet standard noise rules, or if its exhaust would damage the upper atmosphere, economics and performance would not matter: The airplane would not be built.

The NASA team evaluated two approaches to the noise problem. One was a variable-cycle engine, with valves that would divert the airflow around the compressor at subsonic speeds. The other was a turbojet with an effective noise suppressor, which would mix the jet exhaust with outside air, reducing the final exhaust velocity. By that time, in 1994, small-scale suppressors were working well in tests. But variable-cycle engines still looked risky, with complex, hot, highly loaded moving parts. NASA decided to take the suppressed-turbojet route.

The HSCT will have an extraordinary, Winnebago-size noise suppres-

THE ENGINE WILL HAVE AN EXTRAORDINARY, WINNEBAGO-SIZE NOISE SUPPRESSOR.

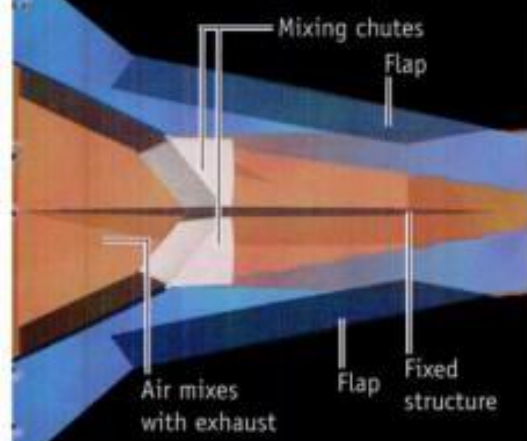


Bigger and Quieter

THE HIGH SPEED CIVIL Transport's engine is nearly three times as large as current military supersonic engines. Designed to last 60,000 hours in service, it uses a range of new materials.

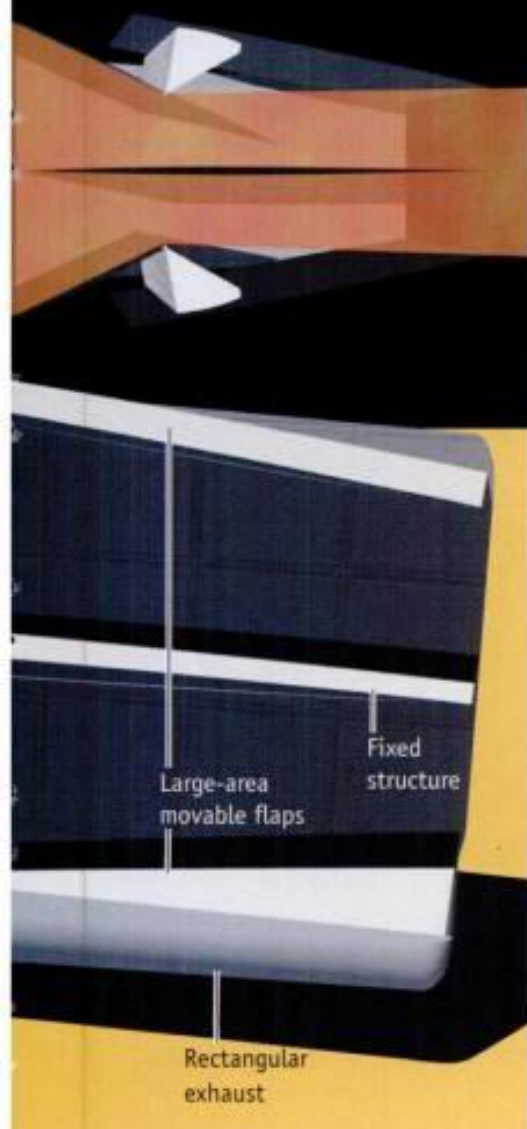
Low-Speed Mode

For takeoffs and landings, chutes deploy into the engine's exhaust stream, mixing air with jet exhaust.



High-Speed Mode

In flight, chutes rotate out and forward, out of the exhaust stream. Flaps also open for the exhaust stream.



sor. "We could hold our meetings in it," says NASA's Joe Shaw, propulsion director for the airplane. For takeoff and landing, large ramps hinge and slide outward, extra inlets open above and below the engine nacelle, and mixer chutes rotate into the exhaust stream. The fast stream from the engine drags 700 pounds of outside air per second through the mixer chutes. The final exhaust is slower and quieter, but produces just as much thrust because of its greater mass.

The other potential HSCT-killer issue was the potential damage of a supersonic aircraft cruising through Earth's protective ozone layer. Burning fuel in air creates oxides of nitrogen (NO_x), which break down ozone into oxygen. Supersonic aircraft engines run at high temperatures, in which NO_x production is greatest.

NASA's solution to the problem was to devise two new combustor designs that eliminate NO_x : One uses a two-stage burn, and the other burns the fuel very rapidly. Late this year, NASA will select the one that appears easiest to build.

Once the engineers had shown that the noise and ozone limits were beatable, a more detailed preliminary design of the airplane and its engine got under way. This started in 1993, and is now close to its final stages.

Today's design not only meets the goals set in 1990, but beats them in some respects.

The HSCT is slender and sinuous. It measures 320 feet from nose to tail—90 feet longer than a 747—but the cabin is little wider than that of a Boeing 737. The fuselage is waisted above the wing, to reduce drag. The forward fuselage droops to improve the airflow over the wing, and the tail is angled upward to clear the ground when the airplane rotates for takeoff. The "arrow" wing combines a deep, sharply swept inner section, which holds most of the aircraft's fuel, with a broad outer wing, which provides low-speed lift.

Recently, the designers have extended the wingspan to 145 feet. This cut a significant 2 decibels off

the noise, because the wing is more efficient, allowing the engines to operate at lower throttle settings.

Unlike the Concorde, the HSCT has an aft stabilizer—this allows the wing to carry effective flaps, boosting lift at low speeds. The final design may have a canard foreplane as well, to damp out flexing in the long fuselage.

The latest aerodynamic refinements used in the HSCT rely on a new form of computational fluid dynamics (CFD). Computers model the airflow over the airplane; these calculations replace much of the work formerly done in wind tunnels. The designers reduced the HSCT's drag by 10 percent by using "nonlinear" CFD codes. Running on supercomputers, these codes model the flow of air molecules in much greater detail than the simpler equations used on most computers, and are particularly helpful with the complex effects of supersonic speed.

One important technology has already emerged from the program's search for new structural materials. Carbon-fiber composites had looked attractive, but none of the resins, which bind the fibers together, could withstand the 350°F temperatures of Mach 2.4. A NASA Langley chemist has developed a new polyimide resin that meets the HSCT's requirements. Polyimides are tough plastic-type materials with inherently good resistance to heat.

HSCT won't share Concorde's characteristic "droop-snoot"—a long, sharp nose section that hinges downward for takeoff and landing, so the pilots can see the runway. Its streamlined nose is fixed in one place, saving more than 3 tons of weight.

A computer will generate a view for pilots based on information from the navigation system, radar, video and infrared sensors, and an onboard database. As a result, there will be no windshield—just small side windows—and the HSCT pilots will look at the outside world through flat-panel synthetic displays. Such synthetic vision renders fog, rain, and darkness irrelevant, and it might very well lead

The Longest Bridge

THE AKASHI KAIKYO BRIDGE in Japan is the world's longest suspension bridge, fulfilling a century-old dream of linking the island of Honshu to the island of Shikoku, both major population centers. In addition to the earthquake zone surrounding the bridge,

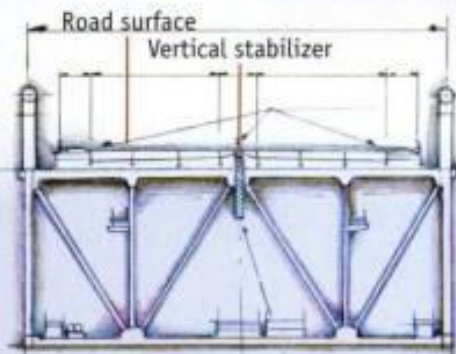
the high winds associated with the region's typhoons were another obstacle to construction. Stresses on the bridge were simulated using a scale model built inside a wind tunnel. Building the bridge meant using new materials and techniques.

Brooklyn Bridge

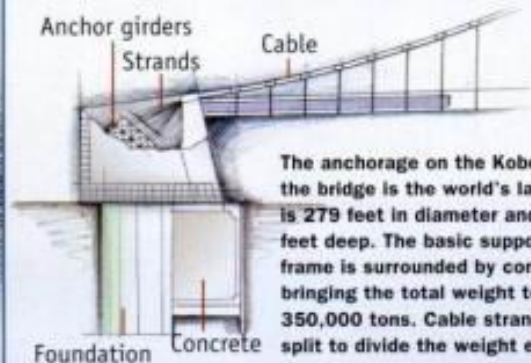


The Akashi Kaikyo Bridge has a span of 12,828 feet, or 2.43 miles. The center span alone is 6,529 feet, or 1.25 miles long. By comparison, the world's first suspension bridge, the Brooklyn Bridge, which was built in 1883, is 1,595 feet long.

Akashi Kaikyo Bridge



A floating crane raised the bridge's girders in sections. Even though the girders are considered strong but lightweight, 90,000 tons of steel were used in their construction. Special vertical stabilizers under the median strip of the deck reduce wind vibration by balancing the pressures on the upper and lower surfaces of the bridge.

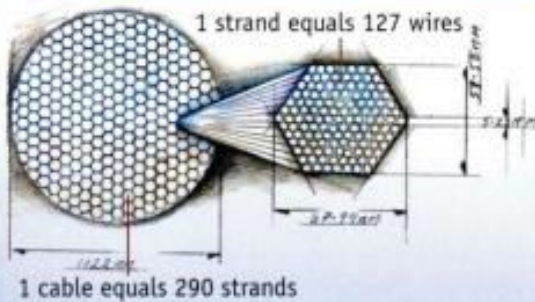


The anchorage on the Kobe side of the bridge is the world's largest. It is 279 feet in diameter and is 207 feet deep. The basic supporting frame is surrounded by concrete, bringing the total weight to 350,000 tons. Cable strands are split to divide the weight equally.



A helicopter flew the pilot rope for the cable to follow.

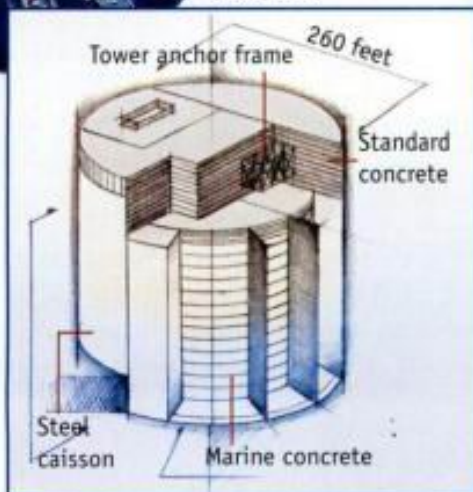
Two cables—one on each side—hold the bridge roadway but each cable is composed of 290 strands. And each strand, in turn, contains 127 wires made from a new, high-tensile galvanized steel. The total length of the wire is 186,000 miles—enough to circle the globe seven times.



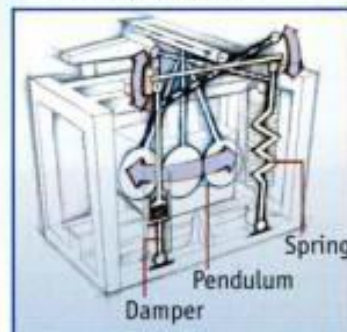
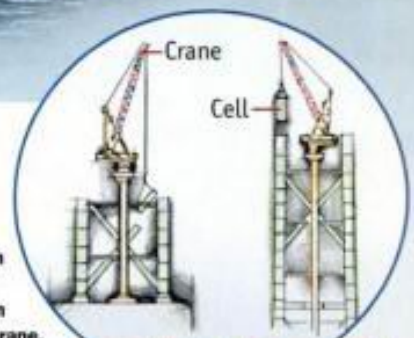
6,529 feet



Factory-made, hollow caissons were towed to the bridge site to serve as the foundation for the bridge towers. Once in place, the caissons were filled with concrete and sunk into the seabed. They support the 100,000-ton bridge.



The bridge towers were built using a boot-strapping crane that constructed the tower one tier at a time. The towers are 30 tiers high, with each tier divided into three sections so as to remain within the lifting capacity of the crane. Mass dampers, weighing 10 tons each, inside the tower work like a pendulum for stability. At 928 feet, each tower is about as tall as France's Eiffel Tower.



INFOGRAPHIC BY DANIELS & DANIELS

ROCKET PLANES

Reusable launch vehicles could revolutionize how we hoist satellites into orbit, deliver packages, and even travel the globe.

By Bill Sweetman

ABOVE EDWARDS AIR FORCE BASE, a C-141A military cargo plane tows a veteran F-106 fighter through the sky on a 700-foot cable. High over the California desert, the cargo jet releases the F-106 for a glide back to the base. The test is a milestone in the development of the Eclipse Astroliner, a reusable launch vehicle designed to deploy communications satellites in space.

The Astroliner is an airplane-like vehicle that will be towed up to 40,000 feet by a Boeing 747, whereupon it will fire its rocket engines and zoom to 75 miles above Earth. After popping its nose open to discharge a satellite, the Astroliner will glide home for a runway landing.

Eclipse Astroliner is only one of several reusable launch vehicles, or RLVs, under development. In Sacramento, a team of ex-NASA engineers is designing a reusable rocket with engines that were built in the 1960s to put a Russian cosmonaut on the moon. On the western edge of California's Van Nuys airport, a 1950s-vintage test facility powered by a

battery of jet engines blasts air through an experimental scramjet engine at eight times the speed of sound. Another team is working on a rocket that lands like a helicopter. Among the backers of RLV development efforts are aerospace legend Burt Rutan, former astronauts Buzz Aldrin and Pete Conrad, and best-selling author Tom Clancy.

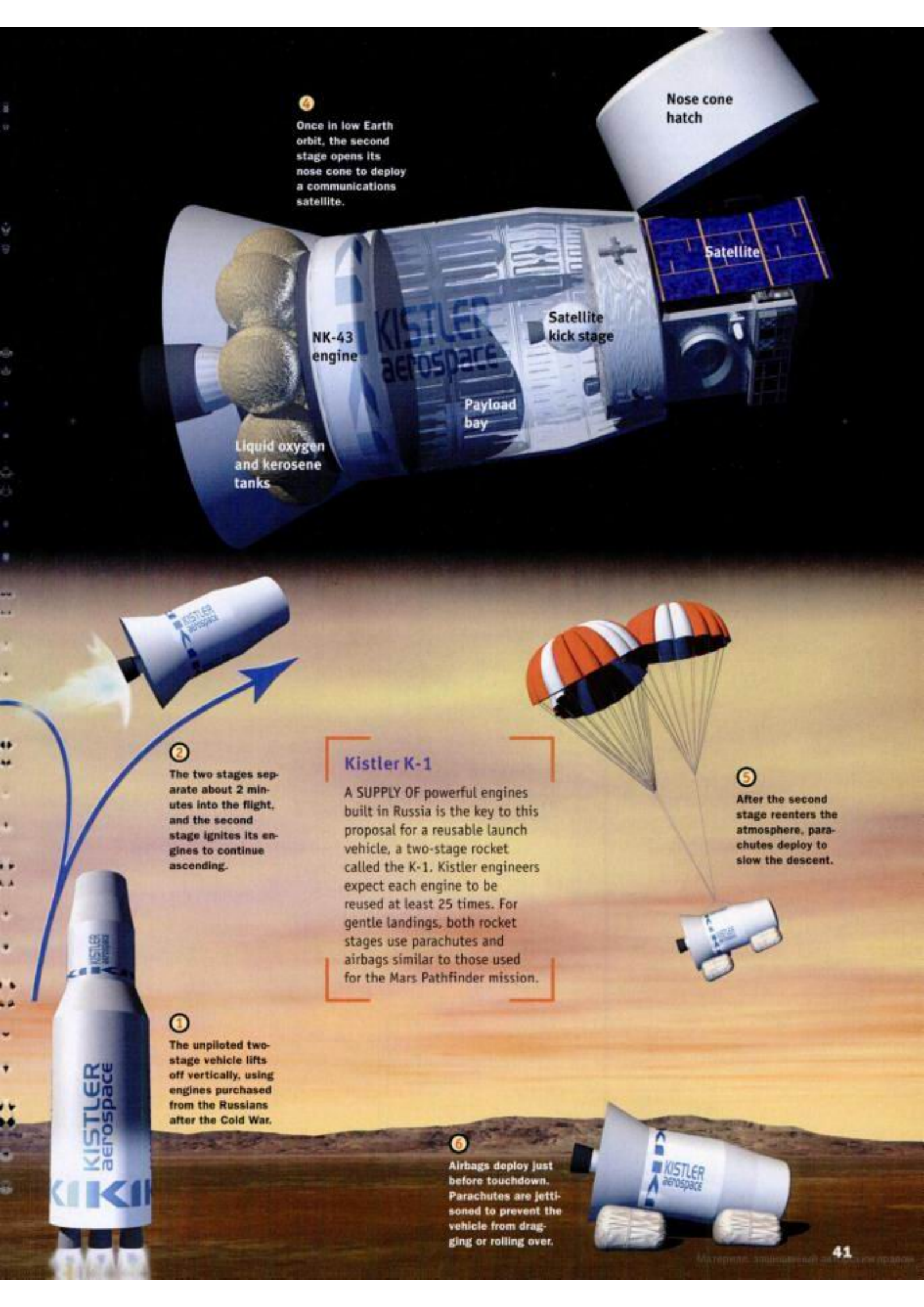
It's all part of a revolution in access to space: a change from big, expensive, one-shot rockets funded by government agencies to smaller, less costly, reusable vehicles designed and built by private industry.

It doesn't take a rocket scientist to see something wrong with how



3 The rocket's first stage flies back to the launch site, landing with the help of parachutes and airbags.

ILLUSTRATIONS BY BOB SAULS/
JOHN FRASSANITO & ASSOCIATES



4
Once in low Earth orbit, the second stage opens its nose cone to deploy a communications satellite.

NK-43 engine

Liquid oxygen and kerosene tanks

KISTLER aerospace

Payload bay

Satellite kick stage

Satellite

Nose cone hatch

2
The two stages separate about 2 minutes into the flight, and the second stage ignites its engines to continue ascending.

Kistler K-1

A SUPPLY OF powerful engines built in Russia is the key to this proposal for a reusable launch vehicle, a two-stage rocket called the K-1. Kistler engineers expect each engine to be reused at least 25 times. For gentle landings, both rocket stages use parachutes and airbags similar to those used for the Mars Pathfinder mission.

5
After the second stage reenters the atmosphere, parachutes deploy to slow the descent.

1
The unpiloted two-stage vehicle lifts off vertically, using engines purchased from the Russians after the Cold War.

6
Airbags deploy just before touchdown. Parachutes are jettisoned to prevent the vehicle from dragging or rolling over.

we launch satellites. Today's throwaway launch vehicles are direct descendants of the first intercontinental ballistic missiles. Using these rockets to launch satellites into low Earth orbit (LEO) costs about \$10,000 per pound, and the cost hasn't dropped much in recent years.

This is bad news for the industry consortiums that want to put more zip into worldwide telecommunications with constellations of LEO satellites. The cost of launching these satellites, and replacing them as they age or break down, threatens to ruin the otherwise promising economics of global phone, data, and video services.

Lower launch costs are the aim of the NASA/Lockheed Martin X-33 prototype and its operational follow-on, VentureStar ["VentureStar: 21st Century Space Shuttle," Oct. '96]. But VentureStar won't fly until 2004 at the earliest, and its first task

may well be to replace the shuttle. Designed to launch sections of the International Space Station, VentureStar is also awkwardly big for the small LEO satellites.

That makes the satellite market a plump target for a group of small startup companies that plan to build new launch vehicles with funding from private investors. So far, none of the companies has a working prototype, nor more than a few dozen employees, and it's likely that some of them will run out of money before they get the job done. But it's also quite possible that one or more of these companies will succeed in building the world's first privately funded reusable spacecraft. Such a craft could not only launch small satellites and scientific research platforms, it might also deliver packages or even passengers across the globe much more quickly than can an airplane.

In theory, many different types of reusable launch vehicles can be built. They can be piloted or unmanned. They can take off like an airplane or a rocket. They can blast all the way from the ground to space in one giant step, or they can use two stages to get there. The five startup RLV companies leading the pack all offer different solutions.

The airborne tow tests over Edwards are designed to prove a key element of Kelly Space & Technology's concept for a winged space plane. Michael Kelly is a former TRW executive who started his company in San Bernadino, California, after TRW canceled the launch vehicle project he was heading. From the outset, Kelly says, he wanted a launcher that could fly from any airport, but he knew that a piggybacking vehicle would be limited in size by the payload of the aircraft carrying it. "Then

Pioneer Pathfinder

A FIGHTER-SIZE AIRCRAFT, the piloted Pathfinder is powered by a pair of Pratt & Whitney F100 turbofan engines, and a Russian RD-120 rocket engine that burns kerosene and oxygen. The payload bay could be replaced with a pressurized fuselage, enabling parcels to be delivered to anywhere on the globe in 90 minutes or less.

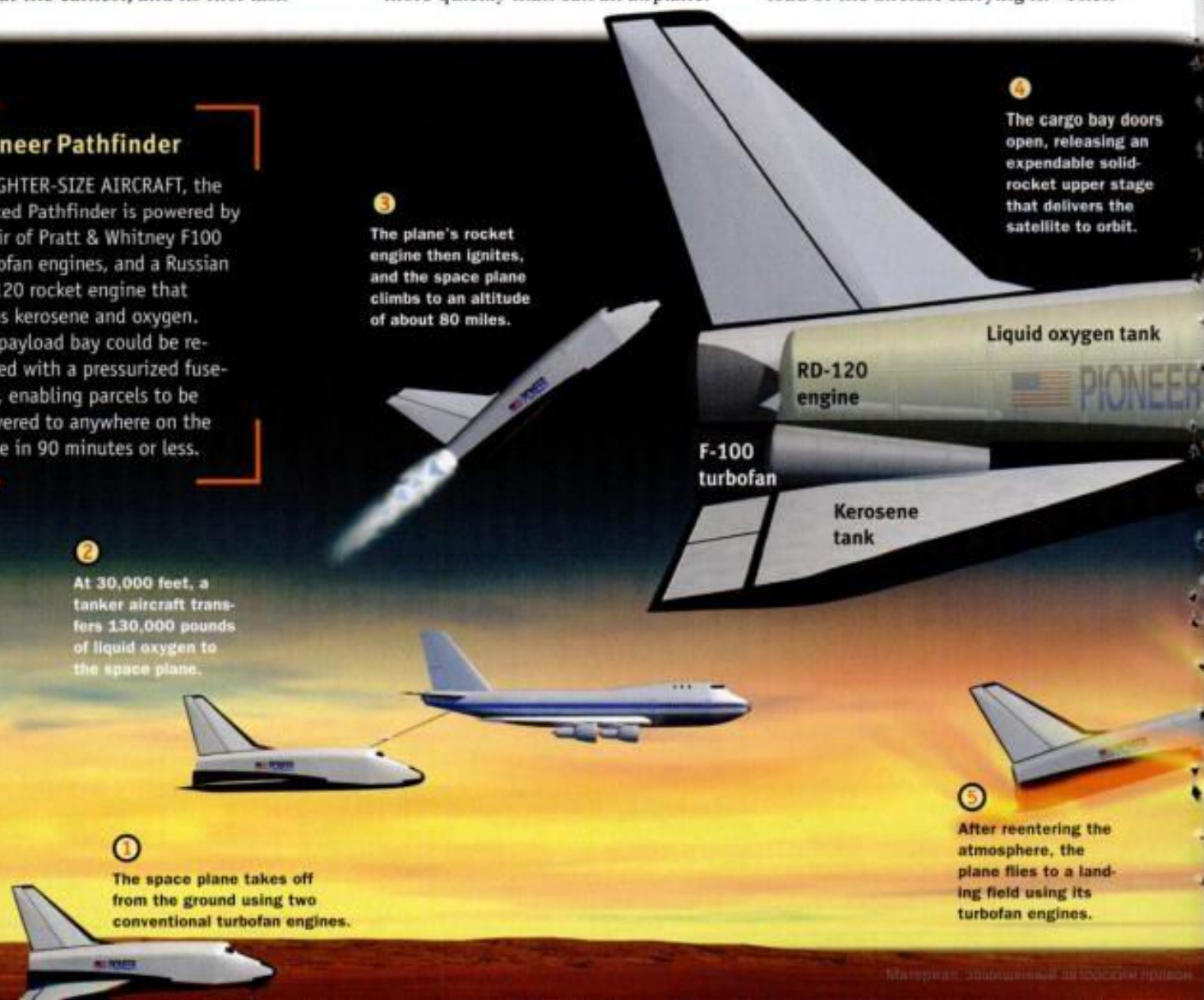
3 The plane's rocket engine then ignites, and the space plane climbs to an altitude of about 80 miles.

4 The cargo bay doors open, releasing an expendable solid-rocket upper stage that delivers the satellite to orbit.

2 At 30,000 feet, a tanker aircraft transfers 130,000 pounds of liquid oxygen to the space plane.

1 The space plane takes off from the ground using two conventional turbofan engines.

5 After reentering the atmosphere, the plane flies to a landing field using its turbofan engines.



we decided to tow the thing, and we got more relief than we dreamed possible," he recalls. World War II tests of giant troop-carrying gliders show that a 747 could pull a 500,000-pound airplane aloft.

Kelly has a \$89 million contract with Motorola to launch 20 of the company's Iridium LEO satellites on the Eclipse Astroliner, starting in July 2001. Meanwhile, the company is building a smaller prototype, called the Eclipse Sprint, scheduled to fly in 1999. About the same size as the F-106, the Sprint will be a testbed for the Astroliner's flight controls, its aerodynamics, and its structural materials—aluminum alloy protected by thermal blankets and tiles. Development of the full-scale vehicle will cost only \$150 million, thanks in part to the use of modified parts from other aircraft.

The Astroliner will be built like a conventional airplane, flown by two pilots, and powered by an off-the-shelf rocket motor. It will not go all the way to orbit, but will reach a speed of Mach 6.5 and an

altitude of 75 miles before its nose pops open and it ejects a satellite, attached to a simple solid-rocket upper stage.

Kistler Aerospace Corp. plans to beat the Astroliner into space, making its first orbital flight late this year. The company's effort began in 1994, when Seattle inventor and entrepreneur Walter Kistler invited financier and developer Robert Wang to join a space launch project. Wang agreed, on the condition that Kistler also take on a manager with experience in an operational space program. The company recruited George Mueller, former manager of the Apollo and Saturn programs at NASA.

Mueller brought in a team of ex-NASA colleagues, who devised a design that he calls "the simplest possible implementation of a transportation system" for lofting LEO satellites. The plan is to build an unmanned two-stage rocket, powered by Russian NK-33 and NK-43 engines burning liquid oxygen and kerosene.

The Kistler K-1 rocket stands 115 feet high, weighs just over 800,000 pounds, and can put about 10,000 pounds into orbit. It looks about as sexy as a feed silo, and its engines—built for the giant N-1 moon-shot booster—have been in a Russian warehouse for a quarter of a century. But Kistler is in the lead among the new entrants, with a contract from Loral Space & Communications to launch 10 of the satellites in Loral's proposed Globalstar mobile phone network.

Kistler and other contenders are using Russian rockets because they are far better than anything made in the United States, which has developed only one new liquid-fueled rocket motor since the Apollo program. The Russians have developed dozens, inventing ways to operate at higher pressure, and applying advanced materials to make their motors more durable.

Kistler plans to fly K-1s from the Nevada test site and Woomera, Aus-

tralia; the latter will serve the Asian market. The company does not intend to sell its vehicles or its technology, but to set itself up as a complete launch service, at \$17 million a flight. That translates to a satellite-delivery cost of about \$4,800 a pound, less than half the current cost. The plan is to build five vehicles, each capable of making 100 flights. So far, the company has secured about \$100 million of the \$500 million needed to complete the project.

Pioneer Rocketplane's Pathfinder, like Kelly's Eclipse Astroliner, has a pilot and needs a "kick stage" to orbit a satellite. The Pathfinder, which looks like a small space shuttle, takes off using two Pratt & Whitney F100 turbofan engines and climbs to about 30,000 feet. There it receives liquid oxygen from a tanker aircraft, through a vacuum-jacketed hose. Only then does it ignite its Russian RD-120 rockets and fly above the atmosphere to release the upper stage carrying the satellite.

Like towing, midair refueling boosts performance because the vehicle starts with full tanks at 500 mph and 30,000 feet. Also, if the rocket does not have to operate in the dense lower atmosphere, it can have a larger-diameter nozzle that is more efficient at high altitude.

Pioneer's team, which includes experimental aircraft designer Burt Rutan and man-on-the-moon Buzz Aldrin, has won a \$2 million design contract under NASA's Bantam program. NASA is looking for a vehicle to launch small payloads (about 400 pounds) for \$1.5 million per flight, and may fund the Pathfinder prototype if it proves competitive.

The Pathfinder is smaller than the Eclipse Astroliner, because its size is limited by the amount of liquid oxygen that an L-1011 tanker can carry. The space plane weighs 220,000 pounds when it disconnects from the tanker, and can orbit a maximum of 5,000 pounds. The airframe is made of aluminum, covered with thermal-barrier tiles like those used on the B-2 bomber's jet exhausts.

Satellite

Crew

6

The space plane makes a conventional, powered landing on a runway.



Rotary Rocket—a team of entrepreneurs backed by private investors, including author Tom Clancy—has developed another unique approach to space launch. The Roton is

a single-stage vehicle that takes off like a conventional rocket, powered by an engine that burns kerosene and liquid oxygen. The engine has an advanced aerospike nozzle, which resembles a traditional bell nozzle turned inside out.

Built into the Roton's nose is an unpowered rotor with telescoping blades that deploy and spin up as the vehicle approaches its landing spot. In the seconds before touchdown, the rotor blades pitch up, trading rotational momentum for lift, and the vehicle lands slowly like a helicopter.

Constructed from graphite composite materials, the 52-foot-

high Roton C will weigh 325,000 pounds at launch—less than half the mass of the Kistler K-1. Its designers, among them Burt Rutan, claim the Roton will be able to launch payloads for as little as \$1,000 per pound, and will be capable of returning with a fully loaded cargo bay. Test launches of the Roton are due to start in 1999.

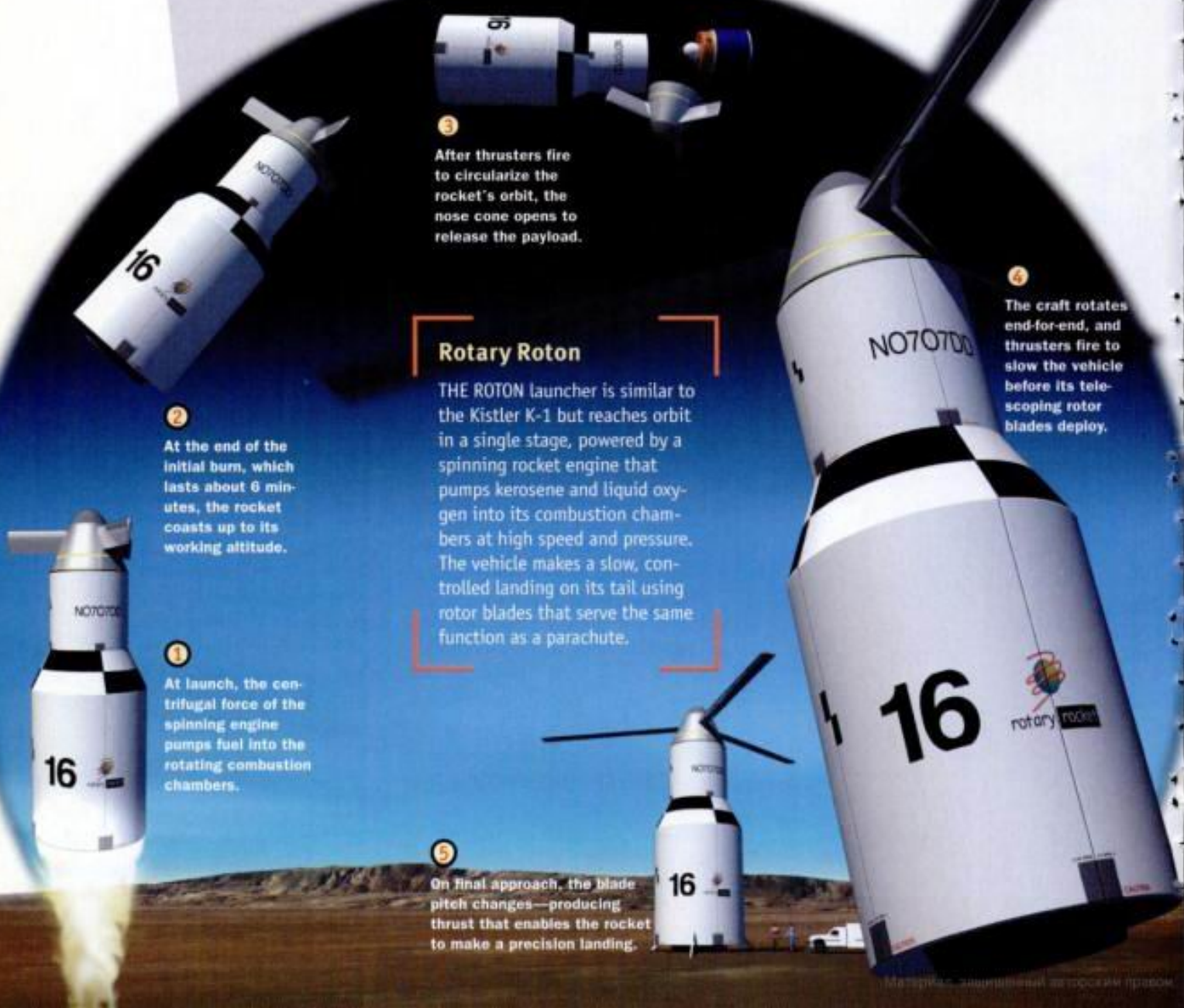
Kelly, Kistler, Pioneer, and Roton publicize their programs on the Internet and in glossy brochures. Not so for Space Access. Based in Lancaster, California, a few miles from the Lockheed Martin Skunk Works, Space Access is the closest thing to a "black" military program that you'll find in the commercial world. Subcontractors and potential customers are

bound by strict non-disclosure agreements. Even suppliers don't know all of the details of the project.

Space Access has about 50 employees—a mix, says President Steve Wurst, of veterans who worked on high-speed programs such as the X-15; and young, computer-savvy engineers. Wurst says Space Access has not publicized its activities because enough investors are already onboard to fund the project, and the company wants to maintain its technical lead over the competition.

The Space Access launcher is a two-stage vehicle, with an airplane-like first stage that takes off and lands on a runway.

The key to the launch system,

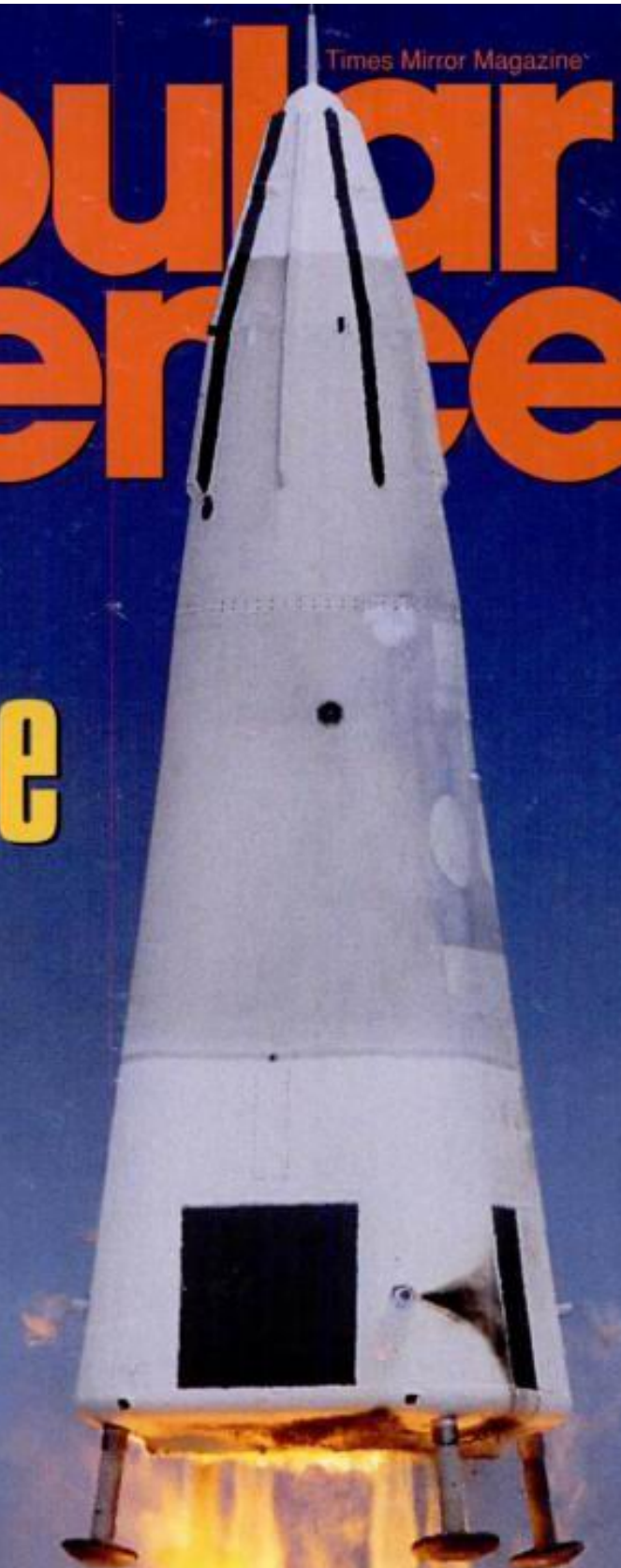


Popular Science

Times Mirror Magazine

Reusable Rocket Ships

LOW-COST
RIDES TO
SPACE

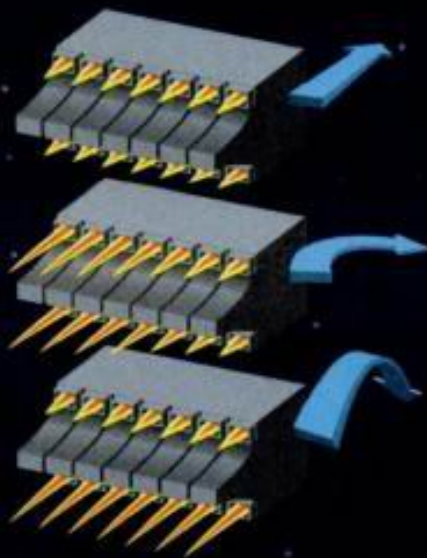


FEBRUARY 1994
\$2.50
CANADA \$2.95



Aerospike Steering

Linear aerospike engines steer the vehicle during its ascent. In these engines, exhaust gas exits from nozzles positioned around the perimeter of a rectangular metal "spike." An automatic flight control system independently adjusts the throttles on the upper and lower modules of the seven engines to control pitch, roll, and yaw. For example, increasing the throttle for the lower modules, and decreasing it for the upper ones, makes the vehicle pitch downward.



Payload bay is removable, so satellites or other cargo can be loaded and tested before the launch date.

Body flaps help control flight at high speeds.

Large angled fins and small vertical fins steer the vehicle during descent and landing.

Fuel tanks made of carbon fiber contain liquid hydrogen.

VentureStar reusable launch vehicle lifts off vertically from a launch pad.

VentureStar lands horizontally on a runway.

A fuel tank in the nose contains liquid oxygen.

VentureStar: 21st Century Space Shuttle

A wedge-shaped reusable rocket with a revolutionary engine will provide cheap rides to space.

By Bill Sweetman

WE HAVE SEEN THE FUTURE of space launchers, and it looks like a potato. A potato with a '61 Cadillac rear end.

That's the shape of the X-33, an experimental aerospace vehicle that will fly in early 1999, lifting off vertically like a conventional rocket, reaching speeds of more than 11,000 mph, and gliding to an airplane-runway landing. In July, NASA selected Lockheed Martin's Skunk Works to build and test the X-33. The wingless vehicle will be broad and rounded, with large stabilizing fins sprouting from its chopped-off tail. No cockpit will break its smooth contours, because the X-33 will have an autonomous flight control system instead of a pilot.

The X-33 will be a demonstration vehicle, the first step toward building a larger reusable launch vehicle called VentureStar, which will be able to lift a 40,000-pound payload into orbit at one-tenth the cost of today's launchers. VentureStar is the most likely replacement in sight for the aging Space Shuttle.

VentureStar is needed because NASA is in a trap. The agency wants a space station. To build and support it, NASA needs a launch system that can lift people

INFOGRAPHIC
BY
JOHN
FRASSANITO
&
ASSOCIATES
AND
SLIMFILMS

Launch date
Height
Liftoff weight

Space Shuttle



1981

184 ft.

4,500,000 lbs.

X-33



1999

67 ft.

273,000 lbs.

VentureStar



2004

127 ft.

2,186,000 lbs.



VentureStar shown releasing a satellite. Its goal: to reduce cost of payload launches by 90%.

and heavy loads into space. The Space Shuttle can do both, but it costs \$500 million a flight, and there are doubts about its safety. NASA needs a new launcher, but it cannot afford to build one unless it stops flying the Shuttle, a political impossibility.

In 1993, NASA Administrator Daniel Goldin set up a special commission to find a way out of the dilemma. The team concluded that the most promising solution was what some people had hoped the Shuttle would be: a reusable rocket that would go into orbit without the aid of jettisonable boosters or a throwaway fuel tank. To find the best design for such a rocket, NASA sponsored a competition. The prize: a contract to build the X-33.

From the start, there were two obvious candidates. Shuttle builder Rockwell International teamed up with Northrop Grumman to design a reusable launch vehicle that looks like a modified Shuttle, stretched to accommodate fuel tanks. McDonnell Douglas Aerospace pitched in with its Delta Clipper, shaped like an inverted ice-cream cone and designed to land vertically on stumpy legs. The third entry, from the Skunk Works, was more of a surprise, because most of the company's high-speed work had been kept under wraps.

The Skunk Works X-33 design dates back to a 1983 design study for a Shuttle-shaped, rocket-powered "trans-atmospheric vehicle" for the Air

Force. The Skunk Works continued to work on this technology until mid-1988 under a classified project code-named Have Region. David Urie, the Skunk Works manager for high-speed programs, recalls that it was in the early 1990s "when I was overcome by the conviction that we were on the verge of being able to do single-stage to orbit" with a rocket. He started to put together a design that blends Have Region technology with a wingless, flattened "lifting body" glider. Lockheed Missiles & Space had studied the lifting body for NASA as a potential "lifeboat" to bring astronauts home from a space station in an emergency.

NASA selected Lockheed to build the \$1 billion X-33 because its lifting-body design offered higher performance at lower cost than its rivals and because the company proposed a more extensive demonstration program for the same money. Another factor may have helped Lockheed win: The X-33 could draw some technology from secret Air Force programs.

The design of the X-33 and the way it is being built would raise this suspicion even if it were not a product of the Skunk Works, the world's premier secret-airplane shop. The X-33 relies on a number of technologies that ostensibly have never been tested in flight. Some long-time observers of NASA and Lockheed see this as strangely risky behavior. "You're seeing two organizations act-

ing out of character," says John Pike of the Federation of American Scientists. NASA is known for cautious engineering and a resistance to untried ideas from outside its own walls, while Lockheed has resisted pressure to share in high-risk projects.

Paul Czysz, a former McDonnell Douglas engineer, points out that it usually takes at least eight years of development before a brand-new rocket engine can be used to launch a vehicle. "There has to be a tested engine out there," he says. Both Czysz and Pike believe that a rocket-powered aerospace vehicle has been built and flown under a secret Pentagon program. But if that's true, Lockheed is not ready to admit it.

Whatever its origins, the VentureStar design is elegantly simple. The designers' first decision was that the vehicle would lift off like a rocket and land like an airplane. Taking off from a runway would require such a heavy undercarriage that the vehicle could carry no payload. Lockheed rejected vertical landing because that would require the vehicle to carry landing fuel throughout the flight.

Lockheed designers also decided to eliminate wings. Conventional airplane shapes, Urie says, "have wings that you don't use until you land, but you have to carry them all the way up to orbit." A lifting body does not produce lift as efficiently as a wing, but this matters little because the vehicle is very light when it returns, minus its payload and fuel. VentureStar will be light enough to land on an 8,000-foot runway, shorter than the runways at most major airports.

Another advantage of the lifting body is that it has an enormous amount of internal space. This is vital for a vehicle fueled by liquid hydrogen, with its very low density. An indication of the lifting body's packaging efficiency is that the 975-ton VentureStar is roughly the same length and width as a Boeing 757 medium-range jet, but it weighs as much as two 747s.

Lockheed paired the lifting body with an engine developed by Rocketdyne. Most rocket engines have round,

A World of Reusable Launchers

NASA'S SELECTION OF VentureStar may spell the end for McDonnell Douglas' Delta Clipper. An improved version, called the DC-XA, has flown a few times, but funding for it ran out in August. A fighter-size space plane called Black Horse may also have a hard time getting further support. Designed by a freelance team led by Air Force test pilot Capt. Mitchell Burnside Clapp, Black Horse takes off from a runway with mostly empty tanks, then meets a KC-135 tanker at 35,000 feet to fill up with fuel for the second leg of its journey. Although Black Horse and DC-XA have been eclipsed by VentureStar, several other projects are still active around the world—at least on paper.—B.S.

X-34 NASA's X-34 will test technologies to be used on a small commercial launcher with a payload of 1,500 pounds. The X-34 will fly in late 1998, reaching a maximum speed of Mach 8, or 5,300 mph, at 250,000 feet. Rockwell and Orbital Sciences Corp. were selected to build the X-34, but withdrew from the project after less than a year, saying it was not commercially viable. Now the project has been restarted with Orbital as the sole contractor.



MAKS Molniya, the company that built the Russian space shuttle, has designed a delta-wing orbiter called MAKS (the Russian acronym for Multipurpose Aero-Space Plane). Perched on a 250-ton fuel tank, MAKS is carried to 35,000 feet by the world's largest airplane, the Antonov An-225. From there, it uses the new RD-701 rocket—burning kerosene, liquid hydrogen, and liquid oxygen—to reach orbit. With two crew members, it can carry an eight-ton payload. The project is stalled for lack of money.



Burlak Another Russian project, Burlak, uses a Tupolev Tu-160 supersonic bomber as a reusable booster. The bomber carries a 28.5-ton two-stage rocket and releases it at 1,200 mph, putting as much as 2,500 pounds into orbit. Lofting a payload of that size from the ground would require a much larger booster. Launch costs will be half those of a conventional booster, according to the Russian missile company Raduga, which designed the rocket. Like MAKS, it is still waiting for funds.



SpaceCab David Ashford, a veteran British missile designer with early experience in space launchers, founded Bristol Spaceplanes Limited to study a reusable launch system that emphasizes safety. Ashford's SpaceCab is a two-stage design. The Concorde-like first stage uses rocket boosters to reach Mach 3.4 and 140,000 feet. The all-rocket upper stage is a delta lifting body, rather like a small X-33. An unusual feature is that the structure is partly pressure-stabilized, like an inflatable boat, to save weight.



REUSABLE ROCKET SHIPS

**Popular
Science**

FEBRUARY 1994

New Low- Cost Rides to Space

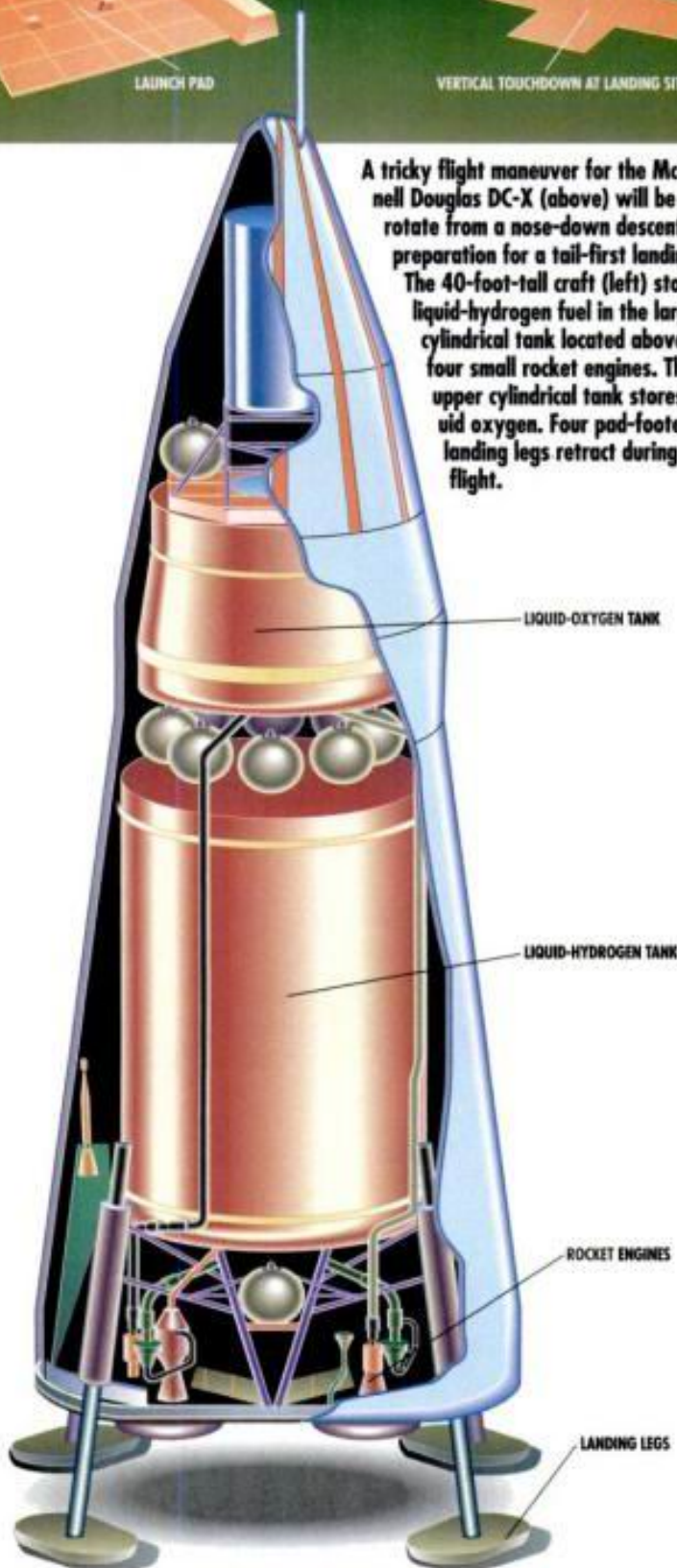
**A new generation
of launch vehicles
leapfrogs past
the space shuttle
and today's throw-
away rockets.**

BY STUART F. BROWN



TECHNICAL ILLUSTRATIONS BY STEVE KARP

A tricky flight maneuver for the McDonnell Douglas DC-X (above) will be to rotate from a nose-down descent in preparation for a tail-first landing. The 40-foot-tall craft (left) stores liquid-hydrogen fuel in the large cylindrical tank located above its four small rocket engines. The upper cylindrical tank stores liquid oxygen. Four pad-footed landing legs retract during flight.



Blasting off from the shimmering gypsum flats of the Army's White Sands Missile Range in New Mexico last September, the McDonnell Douglas Delta Clipper Experimental rocket, or DC-X, rose skyward to an altitude of 300 feet, then slowed to a startling, motionless mid-air hover—as if it were a helicopter. Tilting slightly, the craft next flew sideways for 350 feet. Finally, it began to descend tail-first. Telescoping legs with disk-shaped feet quickly extended, and the rocket used a fiery burst from its four small engines to slow down for a gentle landing. Time aloft was 66 seconds. At the strange craft's touchdown, whoops and cheers erupted from the several hundred onlookers.

Perhaps it does look like something out of Flash Gordon, a bit like a flying gumdrop. No matter. The DC-X has space scientists and engineers more excited than they've been for years. The reason: It could be the harbinger of a first in spaceflight—a truly affordable ride to orbit.

An entirely new generation of economical launch vehicles will be needed if the United States is to stay in the business of lofting commercial, military, and scientific payloads into Earth orbit and beyond. Space-launch accountants know that the major share of the space shuttle's huge cost—\$500 million to \$1 billion per flight, depending on whose numbers you believe—goes toward the 30,000 people who help keep yesterday's technology in operation.

Operating costs are high, too, for the existing range of large, unmanned rockets: the Delta, Atlas, and Titan launchers that evolved from what were originally military ballistic missiles. These rockets have experienced a discouraging spate of failures in recent years, including last summer's \$2 billion explosion of a Titan IV carrying a payload of spy satellites.

Designers hope future craft derived from the one-third-scale DC-X test rocket (one-third the size of a hypothetical craft capable of full orbital missions) or other new launcher ideas being explored will reduce the cost of orbiting a pound of payload to as little as \$500. The government anticipates launching about 39 payloads weighing 25,000 pounds each from 1995 to the year 2030. With the current fleet of rockets, the cost of those launches would add up quickly, at \$3,000 to \$10,000 per pound.

The reusable, single-stage-to-orbit (SSTO) idea represented by the Delta Clipper program has appeal partly because it avoids throwing away expensive hardware, such as the lower-stage engines and fuel tanks used in conventional rockets. But greater cost savings would come from conducting airliner-type operations: Rockets would be serviced, refueled, and quickly relaunched by ground crews that are unthinkable small by current standards. Because it has been built and repeatedly flown, the DC-X is the most visible result of a race to develop a spacecraft that will dominate the world's launch market by getting the job done more cheaply than its competitors can.

Access to Space, a review of the nation's launch-vehicle needs, is being carried out by an interagency group with members from NASA, the Department of Defense, and the Department of Transportation. The team is evaluating several generic advanced-technology launcher designs, including an SSTO rocket, an SSTO air-breathing rocket based on the X-30 national aerospace plane (NASP), and a two-stage-to-orbit (TSTO) combination of an air-breathing first stage and a rocket-powered second stage. It appears that any of the systems could be made to work and could cut space launching costs to 20 percent of their current levels. The TSTO represents a lower-risk, moderate-performance option, while the SSTO concepts are higher-performance alternatives that involve greater technical risks.

In general, the government describes its launching needs



to a group of aerospace firms, leaving them free to develop launch-system proposals based on their individual engineering philosophies and areas of expertise. A winnowing process identifies any technology-development efforts needed to make the most promising ideas work and gets the research rolling. Then an experimental version of the best design is flight-tested and developed into a new national launcher relying on the most advanced technology.

In addition to the Delta Clipper's vertical-launch-and-landing concept, four alternative reusable launcher designs have been proposed. If funding can be found, more than one of these ideas may be developed to see which holds the most promise. They are:

- A winged SSTO rocket that would take off vertically from a launch pad, then glide back for a runway landing. This option carries the extra weight of stubby wings and landing gear rather than the extra fuel a Delta Clipper-style rocket needs to slow itself for a tail-first landing.

- An air-breathing SSTO that would use a small rocket at the end of its runway-based flight to orbit. The ailing X-30/NASP program [see "Whatever Happened to NASP?"] seeks to develop a craft that would avoid the need to carry large on-board supplies of liquid oxygen by using ramjet and scramjet engines burning hydrogen mixed with atmospheric air.

- A vertical-launch, runway-landing, wingless lifting-body design. Lockheed Corp., which is working on the craft, calls it an aeroballistic rocket. The craft's wide aft end would house several rectangular rocket-propulsion units of a type

DC-X IN ACTION

The flight of the DC-X experimental rocket is shown in this multiple image. Takeoff occurs in the lower right-hand corner. A bank of remotely triggered cameras located a few hundred feet from the rocket captured the craft at ten points along its flight path, at approximately eight-second intervals. The ten frames of transparency film were digitally scanned and then composited on a Macintosh Quadra 950 computer. The completed image fills 79 megabytes of disk space, and was transferred onto eight-inch by ten-inch transparency film using a Kodak LVT laser film recorder.

known variously as linear, plug-nozzle, or aerospike engines.

- A runway-based TSTO launcher, which Boeing and NASA have been studying. Boeing's concept uses a large mothership powered by advanced jet and rocket engines to carry an underslung, NASP-like orbiting craft. A NASA configuration puts a rocket-propelled orbiter on top of a mothership powered by turbofans and ramjets. A precursor to both is Germany's Saenger, which features a large Mach 6 turbo-ramjet craft with a small rocket-powered orbiter on its back.

Nobody knows yet whether today's technology can make SSTO flight a reality. Going to space is governed by the physics of rocket science, in particular by a rule known as

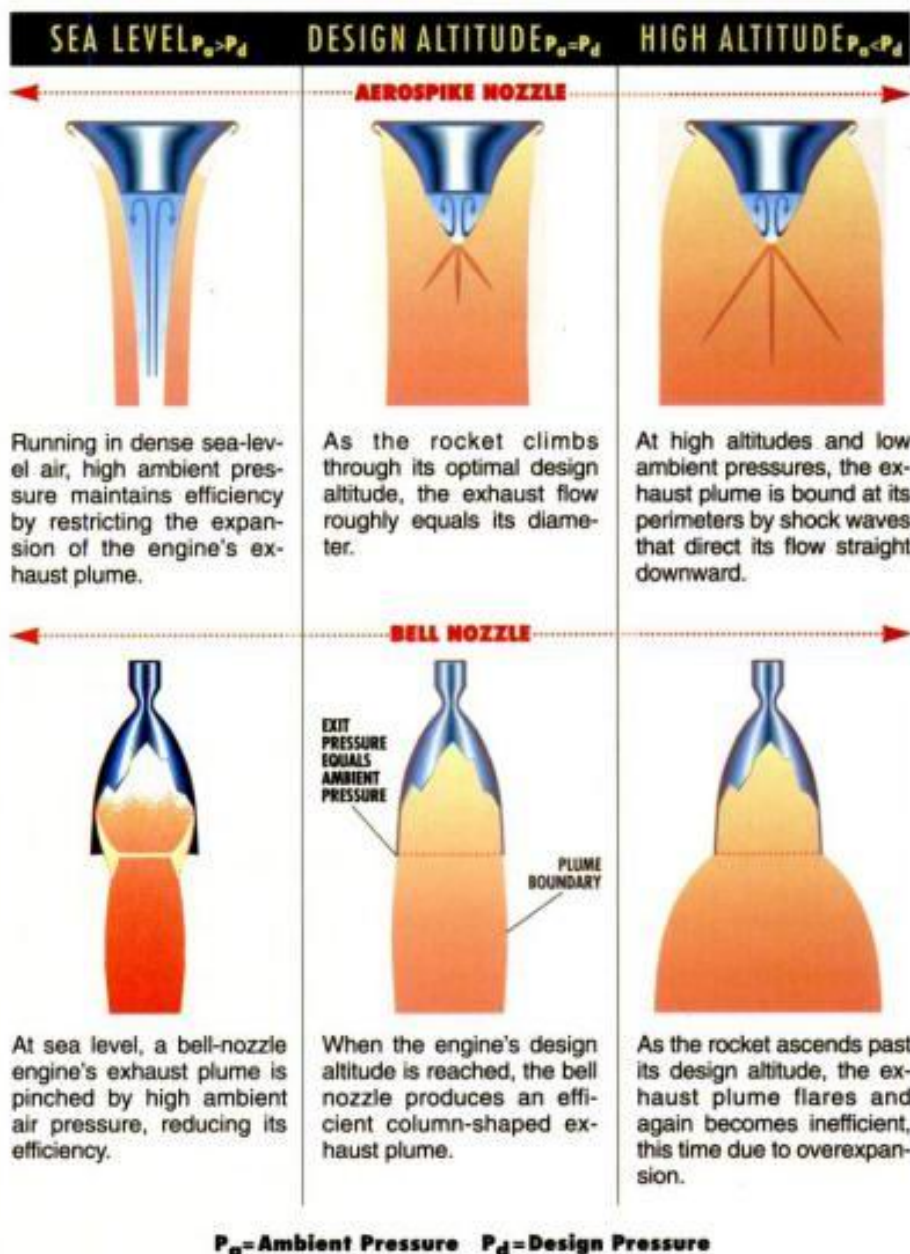
NEW ENGINES FOR NEW ROCKETS

Reusable launchers will need lightweight, highly efficient engines to reach orbit. One candidate is an industrial-strength version of the space shuttle's main engine (SSME). The highly stressed hydrogen- and oxygen-burning Rocketdyne SSMEs are the world's most efficient rocket engines, but they need a major overhaul after each flight to ensure safety. Beefing up the engine's structure, while reducing performance somewhat, could make it reliable for multiple flights without extensive maintenance.

Russia has a contender, too. The "tri-propellant" RD-701 engine built by NPO Energomash is designed to burn a combination of liquid oxygen, kerosene, and liquid hydrogen during the first phase of flight. Kerosene, a dense fuel that produces high thrust to accelerate the fuel-heavy vehicle at takeoff, can be stored in smaller, lighter tanks. During the climb, the engine switches to hydrogen, a fuel that expands into exhaust at higher efficiency because of its much lower molecular weight. The RD-701 has been ground tested, but not yet flown, and needs further development.

A third candidate is the aerospike engine, which replaces the traditional bell-shaped exhaust nozzle with a flat-bottomed inverted cone surrounded by a ring of combustors. A rocket engine's exhaust nozzle controls the expansion of its combustion gases, ideally producing a straight-edged column, and sends the resulting thrust force upward into the vehicle. Bell nozzles produce an exhaust flow that changes shape during flight, as pressure varies from the atmosphere at sea level to the vacuum of space. Thus, the designers must choose a compromise shape that's best at only one point during the rocket's ascent.

The aerospike engine uses shock waves and changing ambient air pressure during the climb to maintain an optimal expansion ratio. "It's an altitude-compensating nozzle without any moving parts," says Rocketdyne director of advanced programs Hank Wieseneck, one of the engine's developers.—S. F. B.



the rocket equation. According to veteran rocket designer Max Hunter, a longtime SSTO proponent and consultant on the DC-X: "The equation says the amount of high-energy propellant you have to carry to reach orbit works out to about 90 percent of the vehicle's takeoff weight, which leaves only 10 percent of takeoff weight for the rocket's structure and payload."

To make room for a useful payload, designers have traditionally built rockets in multiple throwaway stages, each with its own engine and fuel tank. "The only reason for staging was that we couldn't build a light enough structure that could carry all the propellant," says Hunter.

New lightweight materials promise to keep the structural portion of a rocket's takeoff weight low enough so that the craft may be able to lift a payload into orbit with only a single stage. Early aerospace metal alloys used in rockets 20 or 30 years ago have been improved. A weight-saving aluminum-lithium alloy is now available, for example. So are more exotic materials, such as the heat-tolerant titanium metal-matrix composites developed in the NASP program. Modern materials like carbon- and aramid-fiber composites can also be used in interior structures, where temperatures remain in the moderate range.

Using advanced-design rocket engines with high internal temperatures and pressures [see "New Engines for New Rockets"] is the second way designers can push toward meeting the tough goal of fully reusable SSTO rockets. High-performance engine options include a modified version of the powerful space shuttle main engine, a novel "tri-propellant" engine built in Russia, and the promising aerospike design that Rocketdyne and Aerojet have worked on.

McDonnell Douglas was chosen to build the DC-X after a competition in which four aerospace companies submitted designs. The project's \$67 million price was paid by the Ballistic Missile Defense Organization (BMDO, formerly known as SDIO and nicknamed "Star Wars"), which has an interest in promoting research that could cut the cost of launching missile-intercepting payloads. Air Force Col. Simon Worden, BMDO's deputy for technology, has made it clear, however, that the money to build the follow-on rockets needed to prove or disprove SSTO's practicality will have to come from somewhere else.

Hovering, maneuvering laterally, and braking its descent with rocket thrust were critical technical milestones for the 40-foot-tall DC-X, the



The Boeing Company proposes a two-stage-to-orbit (TSTO) launching system that would carry an orbital craft nested in the belly of a mothership (below) to a high-altitude launch point. The mothership Boeing suggests uses

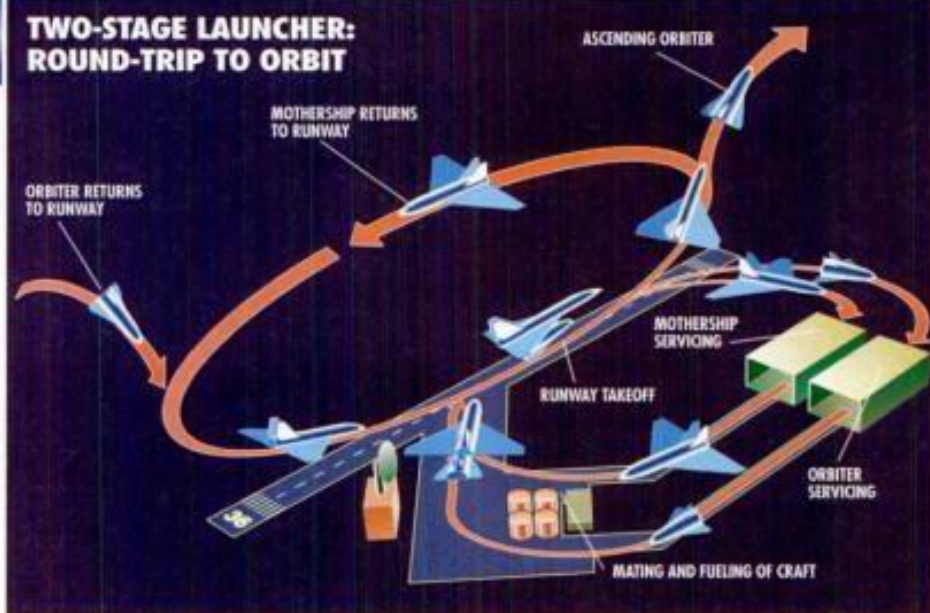


six high-thrust turbojet engines and a single rocket engine borrowed from the space shuttle and mounted between the twin tails. The orbital craft shown at left separating from the first-stage craft is based on the X-30 national aerospace plane design.



TWO-STAGE LAUNCHER: ROUND-TRIP TO ORBIT

Boeing's operational chart (right) shows the servicing, mating, and fueling of the two-stage launch system in preparation for launching from a runway.



product of a program begun barely two years ago. "The bird flies well, and landed right on the center of the pad," reported the flight test manager, former Apollo astronaut Pete Conrad, beaming. "Some of the heat-protective paint turned black, so we'll take the hose and soap and wash it. Then there's no reason not to run it for several more flights to accomplish all the objectives we can with this vehicle."

Further suborbital tests will keep the DC-X airborne longer and take it as high as 16,000 feet. And if someone commits more money, another, larger test craft will be built—the second phase of a three-part effort to build a fully reusable SSTO rocket that can carry people and payloads into space. According to Paul Klevatt, DC-X project director at McDonnell Douglas, "The next step will be a vehicle twice the size of DC-X, which could be flying up to 100 miles—a real space environment—by the summer of 1996." Congress would have to provide several hundred million dollars to build the second-generation test craft, he says.

If the program continues, the technical obstacles will grow more forbidding. DC-X is in the process of demonstrating takeoff and landing, stability and maneuverability, and flight control—directed by a crew of just three, housed in a small, portable operations center. But only about 50 percent of its weight is devoted to liquid-hydrogen and oxygen propellant; its outer body, or aeroshell, is made from a carbon-composite material intolerant of atmospheric heating at supersonic velocities. That limits the first-generation DC-X to airliner-like speeds and altitudes.

One of the goals for a follow-on experimental craft is to use different materials and lighter designs to improve the fuel portion to at least 70 percent of takeoff weight, accord-

ing to Maj. Jess Sponable, DC-X program manager at BMDO. Another, he says, is to demonstrate a thermal-protection system during high-speed, high-altitude suborbital flights that will generate many of the aerodynamic and heating stresses of reentry from orbit. One key maneuver will have engineers biting their fingernails: safely flipping the craft end-for-end from its nose-down reentry attitude

in enough time to fire the rockets for a tail-first landing.

Meanwhile, McDonnell Douglas is looking ahead to a third-generation craft called the DC-Y. A 130-foot prototype orbital rocket weighing about 1.3 million pounds at liftoff, the DC-Y would be able to put a 20,000-pound payload into low Earth-orbit, fly home in one piece, then repeat the feat in a matter of days rather than weeks or months.

NASA, previously unsupportive of SSTO rocket research, has been jolted by the successful DC-X flights into setting up a study called X-2000, which may lead to the development of its own single-stage rocket. Or, the agency might decide to step in and support the continuation of the Delta Clipper effort. Regardless of what NASA does, the Defense Department's Advanced Research Projects Agency and the Air Force, which launches many intelligence and communications satellites, will probably make sure the program doesn't die of starvation.

Backers of two-stage reusable launchers, such as the system proposed by Boeing, argue that the design allows for the weight growth that almost all flying craft experience during their development, without demolishing the launcher's payload-carrying ability.

Boeing's idea is to build a large mothership that would sprint briefly from a runway to an altitude of about



NASA's single-stage-to-orbit concepts include a winged rocket (above) that would glide home to a runway landing. Lockheed Corp.'s Skunk Works advanced development group has drafted detailed plans for what it calls an "aerobalistic rocket." With an unpiloted lifting body design (right), the craft would carry a payload matching that of today's Titan IV rocket in the raised area along its centerline. Liquid hydrogen fuel is stored in the bulges on both sides, with liquid oxygen stored in a trident-shaped tank behind the payload. Lockheed isn't releasing drawings showing the linear aerospike engines arrayed across the launcher's aft end.



100,000 feet and a speed of Mach 3.3. It would then let loose a NASP-like, ramjet-scamjet-powered orbiter nestled beneath its belly. With that free ride, the orbiter wouldn't have to carry the additional propulsion hardware and fuel needed to accelerate from a dead stop on the ground. The mothership would use advanced jet engines being developed in NASA's high-speed civil transport program. Before takeoff, the two unfueled vehicles would be towed into position by airport-style tugs, then mated and fueled. Both craft would be supported by the mothership's landing gear during takeoff, permitting the orbiter to have extra-light gear sufficient for landing with nearly empty fuel tanks.

"I believe that the NASP isn't going to be able to achieve SSTO," says Richard Hardy, vice president of Boeing's military airplanes division. "We feel the NASP guys should think of themselves as a second stage that starts flying at Mach 3, and let us solve the low-speed propulsion problem for them. About 5 percent of the NASP design's weight is landing gear, and that could be what eats up the payload."

David Urie, Lockheed's director of high-speed and space projects, recalls how the idea for the vertically launched aeroballistic rocket came to him. At the time, he was using a company-developed computer program to generate a series of possible shapes for the Assured Crew Return Vehicle, a proposed craft that would rescue and bring home space station crews in an emergency. Some of the wingless, lifting body shapes generated had a thick and wide aft edge.

"I had an 'aha' experience when I was looking at one of those shapes, because I realized it was a perfect place to put a row of linear aerospike engines," he says. Using six or seven of the rectangular, high-efficiency engine modules would give the craft the means to fly back to a runway landing even if one or two failed.

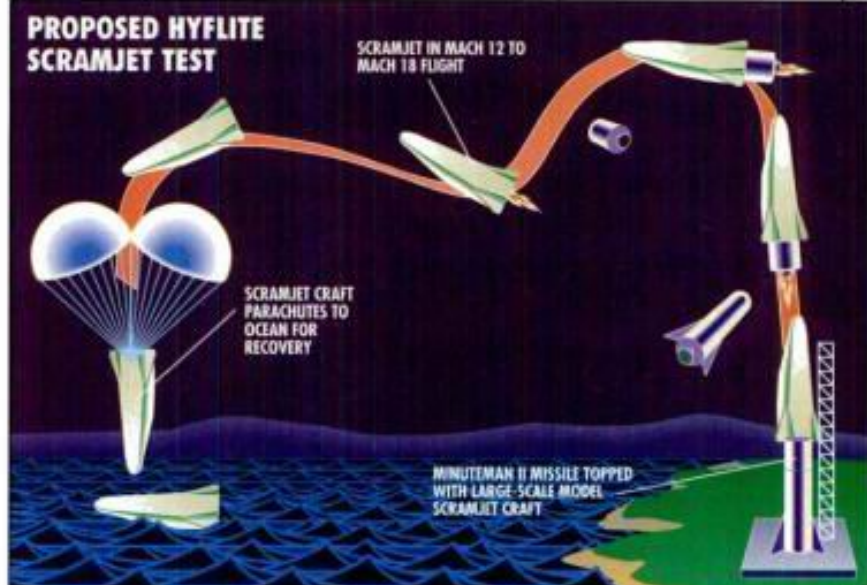
The linear aerospike design works on the same principles as a circular, aerospike engine [see "New Engines for New Rockets"]. A concept that has been extensively tested on the ground, it is arranged as a rectangle that ejects exhaust gas through slots at its top and bottom edges. A truncated rectangular spike located between the slots guides the expansion of the gas flow.

Urie says the linear engines offer weight savings through overall structural efficiency. By feeding fuel into the upper and lower rows of combustors at different rates, the engines can control the craft's pitch angle without the added hardware required to gimbal a conventional rocket engine.

For McDonnell's hoped-for DC-Y to be a winner, the designers must single-mindedly wrestle with the demon of the rocket equation to squeeze in a fuel load accounting for 90 percent of weight at takeoff. Mere grams will count. The engineers know full well that it's better to stay home in bed than let structural weight grow even a sliver of a percent too much—and end up with a rocket that won't make it all the way to orbit, or can't do it with a payload that pays off.

The same harsh equation confronts design teams at Lockheed and any other organization that takes on the SSTO challenge. Is today's aerospace engineering up to it? Maybe two-stage designs—or even a new generation of multistaged, throwaway rockets built with inexpensive, low-tech components—will turn out to be the next way to fly. In the aerospace game, it's nothing ventured, nothing gained.

WHATEVER HAPPENED TO NASP?



One of the most challenging aerospace research efforts ever has been largely discredited and appears to be headed for a crash landing. The X-30/NASP (national aerospace plane) program aims to build a craft that would use an exotic ramjet-scamjet propulsion system. (A scramjet is a ramjet that burns hydrogen mixed with supersonic air flowing through it.) Inhaling atmospheric air, it would fly to very high altitudes and the incredible speed of about Mach 18. Then a rocket would provide the final nudge into orbit.

After several years and an investment of \$2 billion, NASP funding is expected to be cut by about \$20 million in 1994. Useful gains in materials science and other areas have been made, but while an aerospace plane was described and promised, key systems—the engines in particular—are still just laboratory items.

Ben Rich, former president of Lockheed Advanced Development Co. and an expert in high-speed flight, is among those who are skeptical about scramjets. "Nobody has shown me numbers saying that a scramjet has generated net propulsive thrust," after you factor in the steep aerodynamic drag inherent in such engines, he says. The NASP has also met cynicism from overseas. At a 1992 aerospace plane conference, Heinz Pfeffer, head of the European Space Agency's directorate for transportation, said, "NASP is a cover for Aurora [a rumored hypersonic spy plane]. Aurora has achieved its goals and NASP can be allowed to fizzle out."

Nonetheless, some sensible hypersonic testing of technologies needed for the NASP may still take place under a revised research strategy. Jim Mattice, assistant undersecretary of the Air Force for research and engineering, cites a proposed test series called Hyflite [see illustration]. It would culminate in boosting a 30- to 40-foot scramjet-powered subscale test model of an X-30 atop a surplus Minuteman II ballistic missile for a few minutes of Mach 12 to Mach 18 flight. The goal of the six-year, \$2 billion series of nine or ten test flights: reducing propulsion, aerodynamic, and atmospheric-heating uncertainties before building a full-size aerospace plane. One of the conclusions drawn from the Hyflite experiments "could be that this is too hard to do," Mattice says. "But I would say that the chances of the program being successful are greater than 50 percent."

Subscale tests like Hyflite still wouldn't solve the problem of how to flight-qualify a full-size scramjet for service in a manned craft in the same manner jet engines are proven. However, two-stage-to-orbit designs can use a first stage powered by turbofans and ramjets—both well-understood engines. Swapping a scramjet for a ramjet module and flying the craft at its maximum speed would be a way to gain hours of real-world experience. Scramjets and the air-breathing SSTO idea still have backers who believe the potential benefits are too great not to be explored.—S. F. B.

1993 NEW AMERICAN HOME

Popular Science



TINY 4-CYCLE
OUTDOOR
POWER

SECRET

America's
\$1 billion
high flying
4,400 mph
ramjet



SPY PLANE



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OUT OF THE BLACK

SECRET MACH 6 SPY PLANE

**An eyewitness description,
a secret test site, and a new
analysis of advanced aeronautics
paint a portrait of Aurora.**

BY BILL SWEETMAN

Does the U.S. Air Force—or perhaps one of America's intelligence agencies—have a new secret spy plane in action? A growing body of evidence suggests that the answer is yes. A startling disclosure came recently when Chris Gibson, a British oil engineer and highly trained aircraft-spotter, produced a sketch that captured the shape and size of an unusual aircraft he saw during daylight hours in August 1989, flying over his drilling rig in the North Sea. The expert eyewitness's drawing is the keystone that, with other evidence, provides an understanding of a secret hypersonic reconnaissance aircraft that is widely rumored to exist, but routinely denied by U.S. officials. Its nickname is Aurora.

Gibson—a former member of the disbanded Royal Ob-

server Corps, a group of volunteer aircraft-spotters—was able to estimate the strange airplane's length and width by comparing it with the known dimensions of the K-135 refueling tanker and two F-111 bombers flying alongside. But it wasn't until last year, when he came across a magazine illustration of a hypersonic (faster than Mach 5) aircraft design, that Gibson suddenly made sense of the sharp triangular silhouette he saw.

Analysts believe that Aurora is an operational spy plane that replaces the retired Lockheed SR-71 Blackbird. Like its predecessor, Aurora costs several million dollars per flight and is sent out only on missions where the plane's sensors can gather vital information unobtainable by satellite reconnaissance or other means.

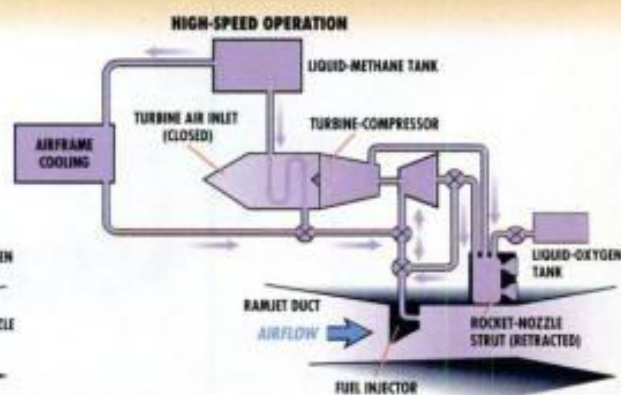
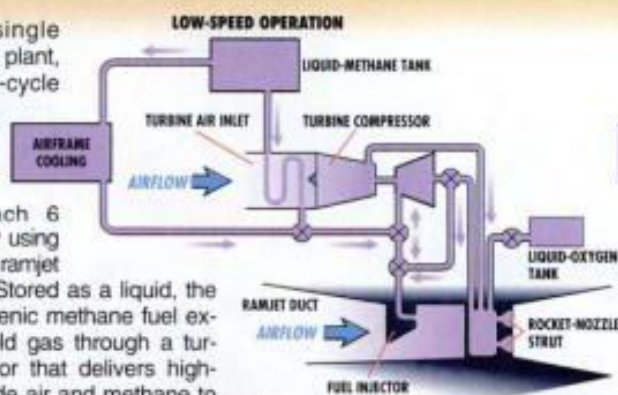
It's plausible that Aurora was used to photograph Iraq



THE COMBINED-CYCLE RAMJET ENGINE

Unlike any single type of power plant, the combined-cycle engine can power an aircraft from a standstill to about Mach 6 (4,400 mph) by using elements of a ramjet and a rocket. Stored as a liquid, the engine's cryogenic methane fuel expands to a cold gas through a turbine-compressor that delivers high-pressure outside air and methane to rocket nozzles in the ramjet duct. At start-up, the mixture is ignited, causing a supercharging effect that draws more air through the duct. During idle, the low airflow rate in the large duct creates a cyclic buildup and release of pressure, producing the loud, low-pitched noises associated with Aurora. Adding liquid oxygen (LOX) to the rocket nozzles increases their exhaust velocity and draws more air through the ramjet, boosting thrust for take-off and acceleration. As ram-effect compression heating begins to occur in the tapered duct, a fuel injector adds more methane, which

combusts downstream of the rocket nozzles. Liquid methane cools the plane's airframe and engines as speed increases, densifying incoming air and adding energy to the turbopump, which augments rocket thrust. LOX flow is gradually reduced to zero at about Mach 2.5, as airflow into the ramjet increases. At higher speeds, the rockets are shut off and the nozzle strut retracted to reduce drag. Now fuel is delivered only through the injector, and the engine runs as a pure ramjet up to about Mach 6.—Bill Sweetman



THREE VIEWS OF AURORA

REAR VIEW



FRONT VIEW



Huge exhaust nozzles (top) dominate Aurora's tail. Rectangular inlets (middle) feed air to the ramjet engines. The contoured underbody (bottom) compresses incoming air and expands exhaust to produce thrust.

IAN WORTH/OLE

during Operation Desert Storm in an attempt to provide tactical intelligence to ground-based military commanders. Aurora's unique capabilities also equip it for surveillance of nuclear proliferation. The list of nations of varying political complexions that covertly possess or are pursuing nuclear arms capabilities includes India, Iran, Iraq, Israel, North Korea, Pakistan, and South Africa. Surprise visits by a reconnaissance aircraft can give intelligence analysts clues—such as the presence of military trucks at an ostensibly civilian plant—which wouldn't be left out in the open when a spy satellite is scheduled to make its pass overhead.

Aurora overflights of Russia have probably not occurred. Such missions would violate an agreement in place since a Lockheed U-2 spy plane was shot down over the Soviet Union in 1960. It is likely, however, that Aurora monitors the submarine-building programs of Russia, China, and other nations from well outside their airspace using side-looking sensors.

Gibson's North Sea sighting completes a puzzle that has obsessed military-aircraft analysts for several years. Consider the following pieces of evidence hinting at the existence of something unacknowledged that flies high and fast:

- In February 1990, the Air Force retired its SR-71 spy planes. The official reason was saving the \$200 million to \$300 million a year it cost to operate the fleet of Blackbirds. Reporters were told that the SR-71's role had been taken over by advanced spy satellites.

TR-3A BLACK MANTA

Somewhat bigger and much quieter than the F-117A stealth attack plane, a stealthy reconnaissance aircraft identified as the TR-3A may already be in service, according to a report by the Federation of American Scientists. The subsonic, unarmed Black Manta's likely role would be to loiter unobserved as far as 100 miles from its target, taking pictures and conducting electronic eavesdropping. Its mission is similar to that of the U-2R, a version of the veteran spy plane still in use, but the Black Manta's targets would probably be unaware of its presence. A small fleet of Mantas (perhaps 20 to 30) may have been produced by Lockheed or Northrop.

MAVIC ERICKSON



The closely guarded Air Force test facility at Groom Lake in southern Nevada is shown in this 1992 photo, taken from a vantage point on public land about 14 miles to the east. Visible are a section of the six-mile runway and, at right, a complex of large, low buildings similar to the B-2 bomber plant in Palmdale, Calif. In front of them are hangars that once housed CIA A-12 spy planes. The secret base has doubled in size since it was photographed in 1978.



- The money saved was less than 7 percent of the approximately \$4 billion the Air Force spends yearly on satellite reconnaissance—mere chicken feed by Pentagon standards. Keeping the SR-71s in reserve would have provided cheap insurance against an unlucky string of satellite and rocket failures, such as the ones that occurred in 1985-'86.

- The Air Force actually discouraged congressional attempts to reverse this termination of its most glamorous aircraft mission. Never in its history had the flying service walked away from a manned mission without a fight.

- The pace of activity at the Air Force's top-secret Groom Lake test site in the Nevada desert has increased dramatically in recent years, suggesting the presence there of one or more secret aircraft programs. By comparing recent photos of the base with ones taken in the late 1970s, it's apparent that several large new buildings were added during the 1980s. Always visible in the recent pictures are a number of chartered Boeing 737 airliners that ferry workers in from other defense-industry towns such as Palmdale, Burbank, or Edwards in Southern California, or from Nellis Air Force Base in Nevada.

- Since mid-1991, unexplained sonic booms have periodically rattled Southern California. Officials at the United States Geological Survey, the agency that monitors earthquake activity, no doubt irked the military with their public statements that a very fast, high-flying aircraft was causing the "airquakes" (see diagram, page 60) registering on their array of seismographs.

- The Federation of American Scientists, a private Washington, D.C.-based policy group, issued a report late last year on the likelihood that unacknowledged military aircraft might exist (see Flying in the Government's Black World). The cautious review of unclassified literature on the subject concluded that several new types of aircraft may indeed be covertly flying around.

It is close to midnight, but all the clocks are set to 0730 Greenwich time. In a closed and guarded hangar, ground crews help two men in orange pressure suits clamber into a delta-shaped, dull black airplane.

MOTHER SHIP

Observers in California's Mojave Desert have reported sighting a large aircraft resembling both the SR-71 and the XB-70, a 1960's Mach 3 bomber prototype. A flat area atop the plane's aft fuselage appears to serve as a mounting point for an unknown object—hence its nickname, "The Mother Ship." Piggyback payloads could include an air-launched satellite delivery vehicle, an antisatellite weapon, or a high-speed aircraft lacking a low-speed propulsion system. A vehicle of this kind could operate discreetly from inland sites, and fly to overwater areas before accelerating to maximum speed and launching its upper stages into orbit or ultra-high-altitude flight. Engineers familiar with aircraft structure, aerodynamics, and stealth design assisted in developing the drawing.

The pilot touches keys that tell computers to start the engines. At first, the aircraft emits a subdued whine, which builds up quickly and is joined by the sound of rushing air. Then there is a flash of light from the intake and exhaust ducts as a wave of noise explodes, rolling harshly across the dry lake bed. Within the roar are the scream of small rockets, the crackling thunder of a huge fighter engine, and a massive pulsing—as low as one cycle per second—that shakes the entire desert base.

Gibson's sighting now makes it possible to reconstruct the Aurora program's history. The spy plane was operational, or nearly so, by August 1989, just before the Air Force parked its SR-71s for the last time. Aurora would have made its first flight by 1986 at the latest, following a development effort that was launched in 1981.

This analysis elicited denials by high officials involved in defense and intelligence matters. Ohio Democratic Sen. John Glenn asserted that his sources in the intelligence community told him there was no such aircraft. "I think they're telling the truth," he said.

Pete Williams, chief spokesman for the Bush administra-

tion's Secretary of Defense, Dick Cheney, gave a standard answer to a query about Aurora. "If there were such a program, we wouldn't discuss it." Williams explained that Pentagon policy says the same answer "must always be given" to queries about secret programs—whether or not they actually exist—to avoid revealing the truth. Donald B. Rice, Bush's Secretary of the Air Force, stated: "There's no program in the Air Force, none anywhere else that I know of. It simply doesn't exist." To some observers the stridency of Rice's response was puzzling. Why didn't he simply utter the usual Pentagon disclaimer?

Black is the adjective most often applied to the hidden world in which such engineering activities unfold. In a 1985 Pentagon budget document requesting production funds for 1987, a censor's slip let the line item "Aurora" appear, grouped with the SR-71 and U-2 programs. Even if Aurora actually *was* the project's name at the time, it almost certainly would have been changed after being thus compromised; "Senior Citizen" is one new label that has been reported. Rated by the Pentagon as an "unacknowledged special-access program," the plane's existence and real name are secret, and therefore deniable.

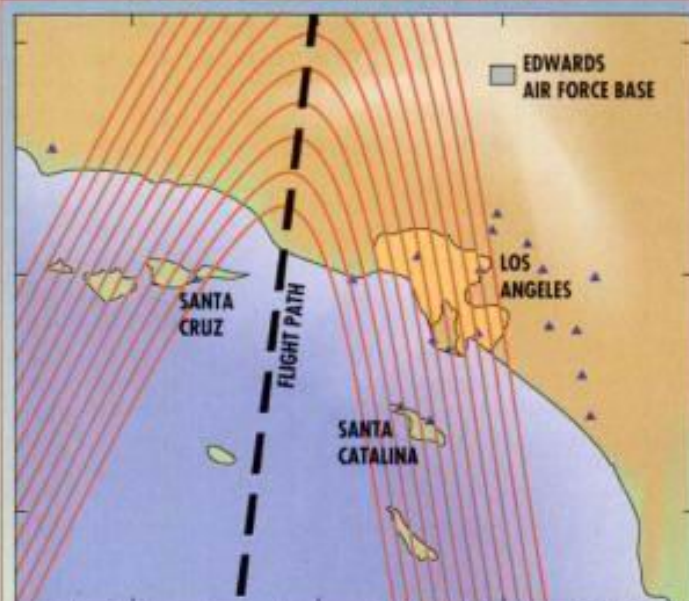
Unconfirmed reports of Aurora's existence first surfaced in 1986, and *POPULAR SCIENCE* conjectured about the airplane's likely design in the November 1988 issue. Now, fresh reports from secret-airplane hunters like James Goodall, who heard and felt bone-shaking sounds coming from the Groom Lake facility late in December, continue to flesh out the picture of Aurora and the technology that makes it work.

Armed with patience and braced for the occasional confrontation with no-nonsense security patrols, resolute observers like Goodall trek through the harsh Nevada desert to a mountainside overlooking desiccated Groom Lake. From several miles away—as close as they can get without entering off-limits government land—the watchers can see the large air base with its motley collection of hangars. Some of the buildings are vast.

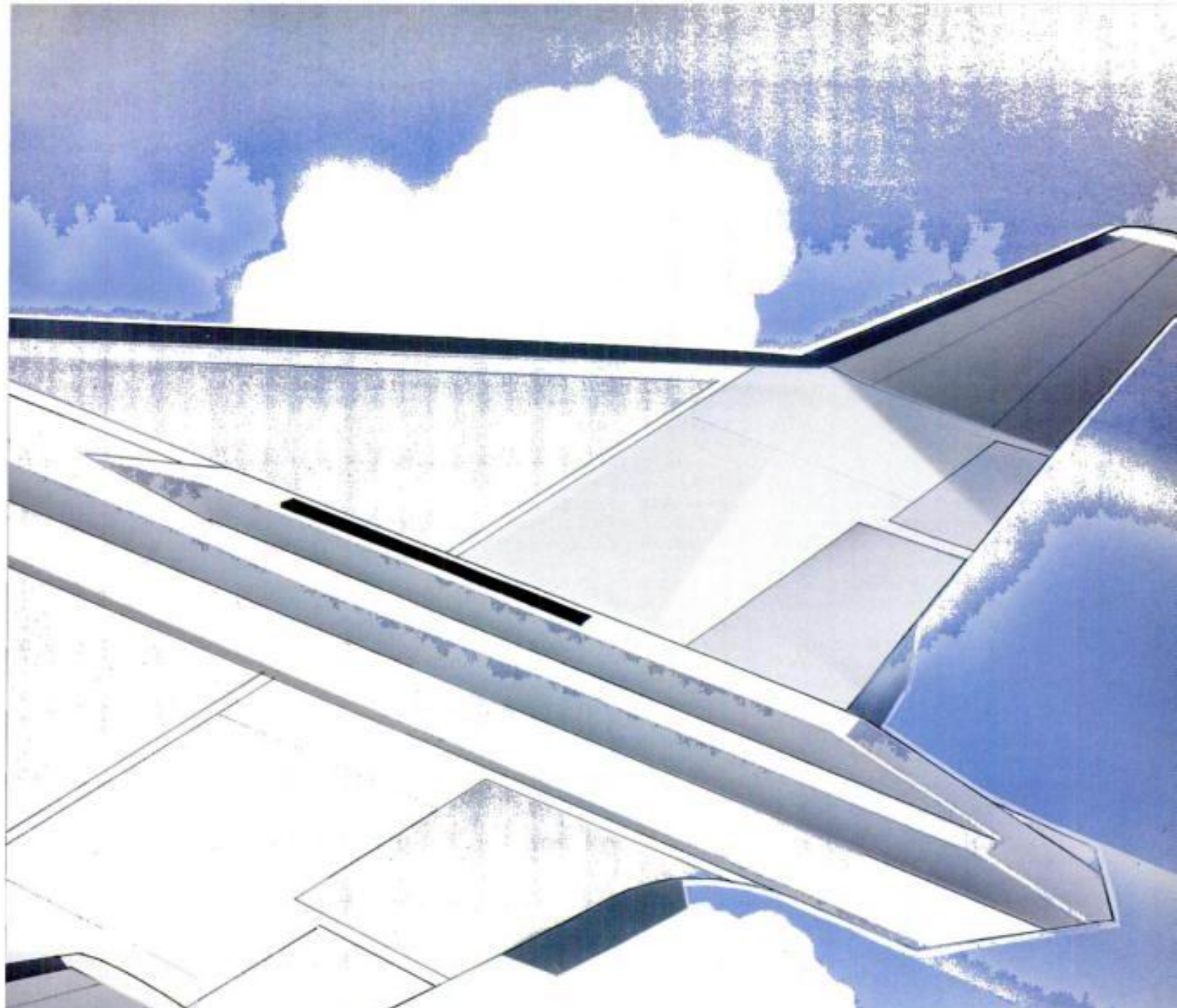
Yet, like a mirage, the isolated facility with its *six-mile* runway doesn't exist—officially, that is. And its non-existence is longstanding. A 1992 Lockheed Corp. paper on the early days of the U-2 program refers to flight-testing at Groom Lake 35 years ago as having occurred merely at "a remote location."

For some, monitoring events on the dry lake bed pro-

AURORA'S FLIGHT PATH



An unidentified aircraft traveling across Southern California at Mach 3.1 on Jan. 30, 1992, jiggled U.S. Geological Survey seismographs with its sonic boom, different from that produced by the SR-71 or the space shuttle. The craft's boom "footprint" traces its flight path toward southern Nevada.



vides the excitement of pursuing a mystery. Author and photographer Goodall, who has been chasing classified programs for almost 30 years, is motivated by enthusiasm for aircraft and a conviction that he's entitled to know how his taxes are being spent. His earwitness account indicates that the airplane's propulsion system is unconventional, to say the least. "We heard Aurora from 18 miles away. The sound is so intense that you feel it. It was quite something else—a pulsing noise that you'll never forget."

The airplane begins rolling forward at half-past midnight, then accelerates and noses up into the sky like a hot fighter. Seconds later it is gone, trailing a shattering roar across the desert. In the cockpit, the pilot sees his course overlaid on a detailed map as the craft climbs through 60,000 feet at a steep 70-degree angle. Just minutes after takeoff, the plane is cruising northeast at six times the speed of sound, covering almost one mile per second. More than 20 miles above the ground, it passes unheard over Montana and North Dakota into Canadian airspace.

Five thousand miles away, a loaded KC-135 tanker lifts heavily into the early morning sky from a secure air base in western Scotland. At a second base farther south, four F-111 crewmen walk toward their pair of aircraft. Only the crew

and their base commander know this will not be a routine training flight.

Aurora was almost certainly built by Lockheed's fabled Skunk Works, now called the Lockheed Advanced Development Co. Of all known design organizations, only the Skunk Works has the proven ability to manage large programs incorporating breakthrough technology in total secrecy. Analysis of Lockheed's financial statements makes it possible to estimate Aurora's price tag at about \$1 billion per aircraft. At most, 10 to 20 of the new spy planes have been built.

A hypersonic prototype paved the way for Aurora. In 1975, Lockheed proposed a small hypersonic research aircraft that would be launched from the back of an early version of the SR-71. And a definitive survey of Lockheed aircraft, published in 1982, stated that the company had already flown a Mach 6 experimental craft.

By the late 1970s the U.S. government probably had two main reasons for going ahead with Aurora. The first: improved Soviet surface-to-air missile (SAM) systems posed an increasing threat to the SR-71, which flies at Mach 3.2 (2,100 mph) and reaches altitudes above 80,000 feet. By 1980, two potent new Soviet anti-aircraft weapons, the SA-10 Grumble and the SA-12 Gladiator/Giant, were under development. Both have a maximum altitude of about 100,000 feet and feature advanced tracking and guidance systems.

FLYING IN THE GOVERNMENT'S BLACK WORLD

The Pentagon's "black world" isn't a mirror-military running parallel to the familiar one. Rather, it is a submerged network of covert activities distributed throughout the armed services and other agencies. Its size can be gauged from unclassified Pentagon budget documents, which include accurate total figures but conceal individual black programs by labeling them with code names or burying them within other categories.

This hidden ocean of funds for research, development, and production of secret equipment amounts to \$16 billion of the Pentagon's \$254 billion 1993 budget. When operations costs are included, the black budget's estimated annual total comes to a staggering \$35 billion.

New construction at the Air Force's secret Groom Lake test facility in Nevada, and the number of workers being flown to and from there in recent years, suggest that a decent chunk of this invisible money is being directed toward several unacknowledged, large-scale aircraft or missile projects under way at the remote site.

The Air Force has hidden major aircraft programs before on two occasions. A giant Lockheed airplane called the CL-400 was the U-2 spy plane's intended replacement. Code-named Suntan, the Mach 2.5 aircraft was to be powered by radical hydrogen-fueled engines.

Lockheed had virtually completed the first four aircraft before Suntan was canceled in 1958 due to technical snags. The project cost \$250 million in fat 1950's dollars. Not one word leaked out about Suntan until 20 years later, when Lockheed started talking about liquid hydrogen as a future aircraft fuel.

Suntan was replaced by a CIA project for a Mach 3 spy plane called Oxcart. After Lockheed was selected to build the plane, it was renamed the A-12. It first flew in April 1962 from Groom Lake, which was made into a fully equipped base supporting A-12 flight testing and the CIA's dozen operational planes.

The Air Force subsequently ordered 30 SR-71 reconnaissance-strike aircraft derived from the A-12 prototype. The existence of the SR-71 was disclosed in a 1964 statement by President Lyndon Johnson. But the CIA's A-12s flew secretly until mid-1968, and they were not revealed to the public until 1982. Through a combination of tight security and disinformation, the A-12 program was concealed for 23 years. Now ask yourself: Would your government lie to you?

In "Mystery Aircraft," a report released last year, the Washington, D.C.-based Federation of American Scientists (FAS) concluded that two or more types of secret airplanes are likely to exist. Based on an extensive analysis of unclassified Pentagon and corporate financial documents, technical papers, and a range of news reports, the study favors the view that some of the reported aircraft are prototypes, while at least one may be in regular service.

"It is probable that at least one high-speed, high-altitude experimental air vehicle is currently undergoing flight tests," or may possibly have achieved operational status, the report states. The craft could be manned or unmanned, it notes, fitting either the general description of a Mach-4 to Mach-6 Aurora or a faster Mach-8 "exotic propulsion aircraft" using pulse-detonation or external-combustion technology to reach hypersonic cruise speed.

The "doughnuts on a rope" exhaust contrail ["Science Newsfront," Aug. '92] photographed last year in Texas might be the product of a pulse-detonation type of engine, which combusts its fuel in intermittent bursts. An aircraft using external combustion at high speeds would fit the description of a vehicle dubbed "The Pumpkin Seed" (see drawing).

According to the FAS study, "There is also the possibility that the SR-71 follow-on is

hidden in plain sight" within the National Aerospace Plane (NASP—also known as the X-30) project, which is aimed at developing an air-breathing hypersonic craft that can climb into low-Earth orbit from a runway in a single stage. Knowledge about propulsion and high-temperature structures gained in the NASP program may have proven applicable to a Mach 6 to Mach 8 aircraft now flying.

As many as a few dozen examples of a subsonic stealthy reconnaissance aircraft called the TR-3A or "Black Manta," probably built by Lockheed, may currently be in production or operational, the FAS analysts say.

Finally, it is highly probable that some one- or two-of-a-kind stealth aircraft prototypes exist, the study concludes. Such aircraft would be built to test concepts intended for the B-2 bomber, the TR-3A, the Navy's canceled A-12 stealth attack plane (no relation to the SR-71's predecessor), or other aircraft. These planes could account for the number of different mysterious aircraft described in sighting reports.

Putting aside the romance of sifting clues about secret airplanes possessing wondrous characteristics, the authors of the FAS report raise a broader fundamental question: With the Cold War behind us, what's the effect of continuing to support such vast and costly secret defense activities?

The hard-nosed answer is provocative: "Secrecy tends to obstruct technological development by inhibiting communication of useful information, increasing costs, generating public mistrust, and all too often promoting fraud and abuse," the study says. "It is being used to protect controversial programs from public awareness, more than from hostile intelligence services."

Recent major examples of secrecy masking incompetence include the B-2 stealth bomber program, which has been shot through with cost overruns and performance shortcomings, and the disgraced Navy A-12 program, which was killed after billions of dollars of misguided expenditures.

The sentiment expressed by FAS is gathering broad support in Congress and elsewhere. Its message to the Pentagon is this: Unjustified secrecy is anti-democratic. —Bill Sweetman and Stuart F. Brown

Black, fast, and retired. The military insists there's no successor to the SR-71.

The second reason for building Aurora was that satellites alone are not the best solution to reconnaissance requirements. While they take superb pictures, satellites also have inherent limitations. They follow fixed, predictable orbits, which make their appearance no surprise to a shrewd adversary. Although earthbound controllers can command satellites to fire thrusters to adjust their orbits, this ability is strictly limited by a finite on-board fuel supply. In addition, because it is difficult to supply the amount of power needed to operate an all-weather radar, most satellites carry only daylight or low-light cameras.

Although they cost several hundred million dollars apiece, spy satellites last, on average, only five years before they are dumped into the atmosphere and replaced. And it is difficult to increase surveillance quickly in a

crisis unless a stockpile of reserve satellites and launchers is kept ready—as the former Soviet Union once did.

Aircraft are much more flexible. They can be dispatched exactly where and when they are needed, and they can be fitted with day, night, or bad-weather sensors, depending on conditions in the target area.

During the hour it takes to reach the initial point for descent, the pilot and reconnaissance systems officer (RSO) in the backseat are fully occupied with checking equipment to see how it operates in the 1,000°F friction heat soaking into their aircraft's structure. On the way down, the flight profile is computer-controlled—a delicate balance between speed, altitude, and deceleration rate.

Over the North Sea, the tanker and the F-111s gather into



a loose formation and follow a racetrack pattern. Appearing suddenly, the black jet turns in behind the KC-135 and connects with its refueling boom, wavering a little while matching the tanker's low speed. During the next ten minutes, 40 tons of liquid methane flow into the spy plane before it turns away and hurtles skyward. Already, another loaded methane tanker and two more F-111s are preparing to depart their bases in Britain.

An analysis of Aurora's three-dimensional shape can be extrapolated from its 75-degree swept triangular outline. The aircraft corresponds almost exactly in form and size to hypersonic reconnaissance aircraft studied in the 1970s and 1980s by McDonnell Douglas, according to Paul Czysz, now a professor of aerospace engineering at St. Louis University.

Czysz worked on hypersonics while at McDonnell Douglas, including the company's proposal for the National Aerospace Plane program ["X-30: Out of This World in a Scramjet," Nov. '91], and is an acknowledged expert in the field. Efficient hypersonic planes "are basically air-breathing propulsion systems," he says.

Like the SR-71, Aurora has a crew of two. Flying it is quite unlike piloting a conventional aircraft. There is little if any outside view, because a normally angled windshield causes too much drag and gets too hot. For these reasons, Aurora may have a retractable windshield used only for takeoffs and landings; at other times, the windshield would be covered by a heat shield.

Aurora's pilot is really a mission manager, monitoring the

aircraft and its systems and following the course of the flight on large-format video displays. His or her most important function is to cope with the unexpected: shifts in upper-atmospheric temperature, weather developments over the target area or refueling zone, or problems with the plane's mechanical or electronic systems.

The RSO supervises a battery of sensors. The most important is a synthetic-aperture radar (SAR), a side-looking instrument that takes a sequence of snapshots of the target as the aircraft moves and compiles them into a single radar image that is as sharp as if it had been acquired using an antenna hundreds of feet wide. The best SAR images are classified, but have been described as "near-photographic," allowing different types of land vehicles to be easily distinguished from more than 100 miles away, regardless of clouds or smoke.

In clear weather, Aurora uses daylight and infrared cameras for ultra-detailed work. And unlike a satellite, the craft can be scheduled to make its reconnaissance passes at the golden hour for covert imaging: early morning, when the low sun provides even illumination and long shadows that highlight features on the ground, before heat-induced haze forms.

A phased-array antenna built into Aurora's upper surface—near the tail end, where aerodynamic heating is minimal—allows the airplane to transmit real-time or near-real-time imagery to the Pentagon's satellite network.

In a Middle Eastern country, a bored radar operator in an underground shelter fails to notice a faint blip on one edge of his screen. The system's computer can't make sense of

[Continued on page 98]

PUMPKIN SEED

Reports of a brightly glowing aircraft moving very rapidly across the night desert sky at high altitudes may be attributed to the use of external combustion. The exotic hypersonic propulsion method involves igniting fuel released from ports girdling the plane's flattened, diamond-shaped body. Exhaust expands in the conical area defined by its shock wave to produce thrust. Turbojets provide propulsion at low speeds. Here, an exotic propulsion demonstrator is seen as it transitions from a turbojet-type accelerator to external-burning power. In theory, control at high speeds could be provided by modulating the fuel flow to the propelling nozzles. This aircraft may be unpiloted.

MARC ERICKSON



INSIDE THE LOCKHEED F-117A ATTACK PLANE

The polygonal canopy is comprised of five panels of specially coated glass that shields metallic equipment inside the cockpit from radar by reflecting the beams away from their source.

Radar-deflecting stealth principles dictate the faceted, triangular shape of the airplane. Though roomy, the avionics-packed cockpit provides poor side visibility.

The forward-looking infrared (FLIR) turret resides behind a metal screen with a radar-absorbing coating. Its companion, the downward-looking infrared (DLIR) turret, is under the plane's nose.

Screens coated with radar-absorbing material shield the engine-air intakes. Broad, flattened ducts mix the hot exhaust with cool air, greatly reducing its visibility to enemy infrared sensors.

A pair of 2,000-pound, laser-guided bombs are stored in an internal weapons bay between the strike plane's twin F404-GE-F1D2 non-afterburning turbofan engines.

Activating weapons systems was forbidden. But coupling the cockpit experience with interviews, published reports, and gun-camera videos released during the Persian Gulf war gave me a good idea of how the equipment works and what it's like to operate. More important, I learned that the stealth attack plane has more tricks up its top-secret sleeve than just the ability to elude radar.

The Lockheed-built aircraft made a less-than-impressive combat debut in the 1989 U.S. invasion of Panama, when a pair of F-117As missed their bomb target—an empty field next to a barracks. But its performance in Operation Desert Storm erased any doubt about the black airplane's ability to strike unseen in the dark with pinpoint accuracy.

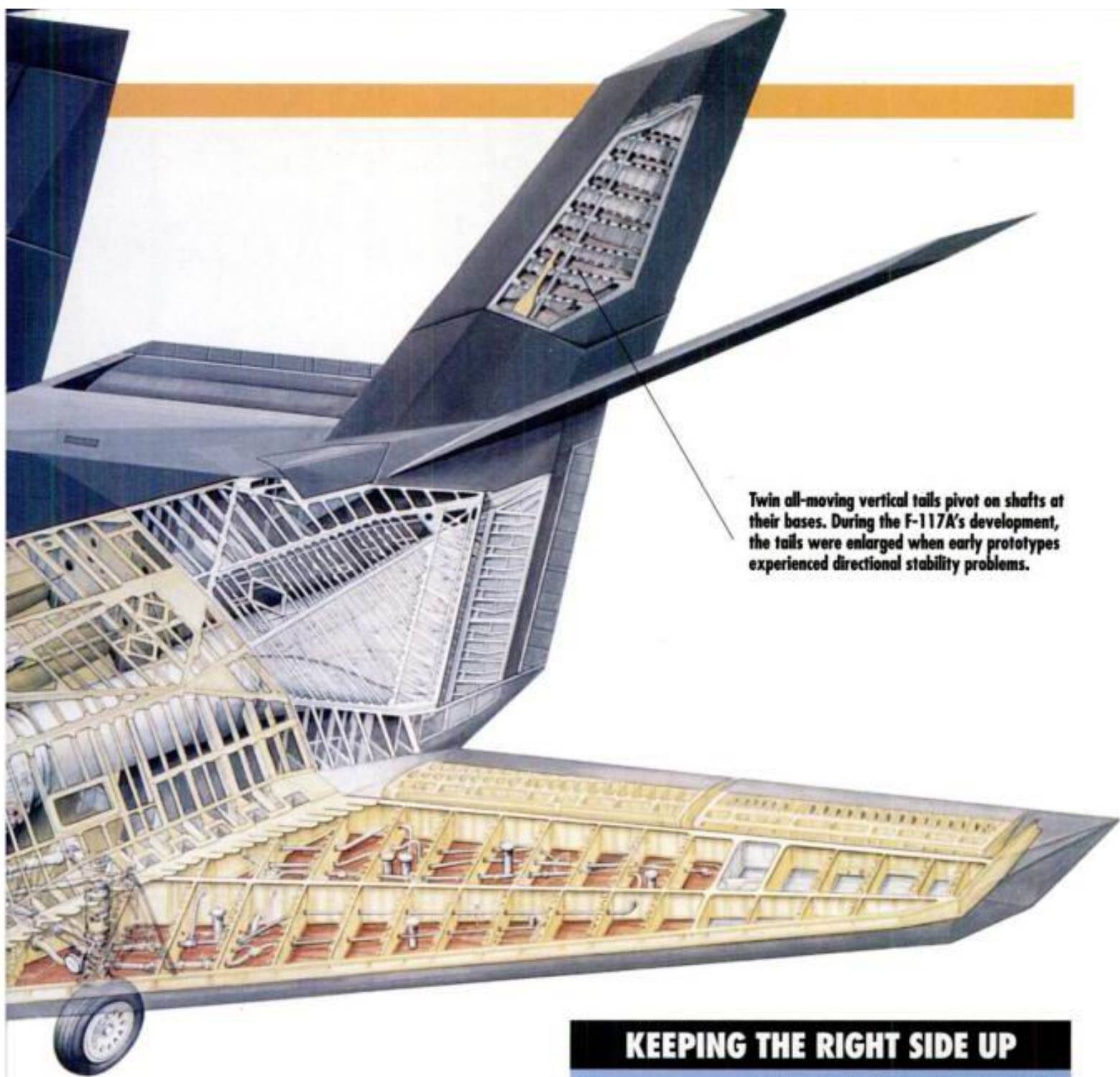
The F-117A was the only manned weapon system that coalition commanders dared to send over central Baghdad's boiling cauldron of anti-aircraft missiles and guns. The planes struck night after night and flew away unscathed, bringing back gun-camera videos that stunned the public with images of bombs plunging neatly down air shafts and blowing out the walls of command centers.

The triangular airplane's success drew attention to its radar-evading stealth characteristics, but the simulator session convinced me that several other capabilities were just as important to its deadly effectiveness:

- The F-117A can literally fly itself to the target and back, even over a complex course that includes turns and altitude changes. An autothrottle helps the airplane arrive over a target at the precise moment mission planners specify. With no telltale lights, radar, or radio emissions permitted, F-117A pilots during the gulf war depended on accurate timing to avoid colliding as they crisscrossed the night skies above downtown Baghdad.

- Cloaked in stealth and free of flying chores, the lone pilot can concentrate on the night-piercing infrared display. He can carefully select a target, mark it, and attack with a minimum of distraction.

- The F-117A appeared to be extremely stable—a critical quality for a bomber—despite a shape that looks more like a crystal-growth experiment than an aerodynamic design capable of flight.



Twin all-moving vertical tails pivot on shafts at their bases. During the F-117A's development, the tails were enlarged when early prototypes experienced directional stability problems.

•In service for a decade, the F-117A is still maturing. Features such as the full-color computer screens I saw are just now being introduced into the operational fleet.

The simulator flight was arranged by the Aeronautical Systems Center at Wright-Patterson Air Force Base near Dayton, Ohio, which manages the F-117A's continuing development. Gary Creiglow, a civilian Air Force engineer who ran the F-117A training system program for more than eight years, was dispatched to supervise my visit.

CAE-Link's simulator in Binghamton checks out new or upgraded equipment before it's installed in the airplanes. Creiglow says the simulator has helped catch some design glitches that could have affected the aircraft's performance. Using the system for debugging new hardware and software also avoids tying up the other F-117A simulator the company has built. Called the weapons systems trainer, the second device is located at Holloman Air Force Base in New Mexico, which is the home base for the F-117As. Access to this machine was denied because of the heavy

[\[Continued on page 105\]](#)

KEEPING THE RIGHT SIDE UP

Enemy weapons aren't the only deadly threat combat pilots face—spatial disorientation can be a killer too. Rapid maneuvers during dogfights or when twisting away from pursuing enemy missiles can leave fliers literally not knowing which way is up. This problem is especially dangerous at night, when ground and sky may merge into a seamless blackness. At least one F-117A pilot who crashed during night training may have died for this reason.

F-117As are now equipped with a unique lifesaving feature: a panic button that lets the pilot turn control over to the airplane. The key to the so-called Pilot Activated Automatic Recovery System is the autothrottle, which lets the airplane adjust its thrust as necessary to recover from stalls or other dangerous situations.

I got to experience this feature in the F-117A simulator. From level cruising flight, I wrenched the control stick until the airplane was in an inverted dive, then pressed a button on the stick. The craft instantly rolled upright and began pulling out of the dive, as a computer screen predicted the altitude at which I would recover.

The system taps into the F-117A's airspeed indicator, barometric altimeter, and inertial guidance system to gauge airspeed, altitude above sea level, and attitude. But it can't detect height above the ground. "The pilot has to look at the predicted recovery altitude and decide whether it is high enough," says simulator engineer Gary Creiglow. "If it is, he can stop sweating. If it isn't, he'd better get out."—T. R. G.

Pantex is a high-security Department of Energy facility named for its location in the Texas panhandle. It is protected by gun-toting guards wearing spit-shined combat boots. "Some of the guys say that if we just took down a couple of fences, it would look like a prison," says administrative program manager Jerry Hemphill, one of nearly 3,000 employees.

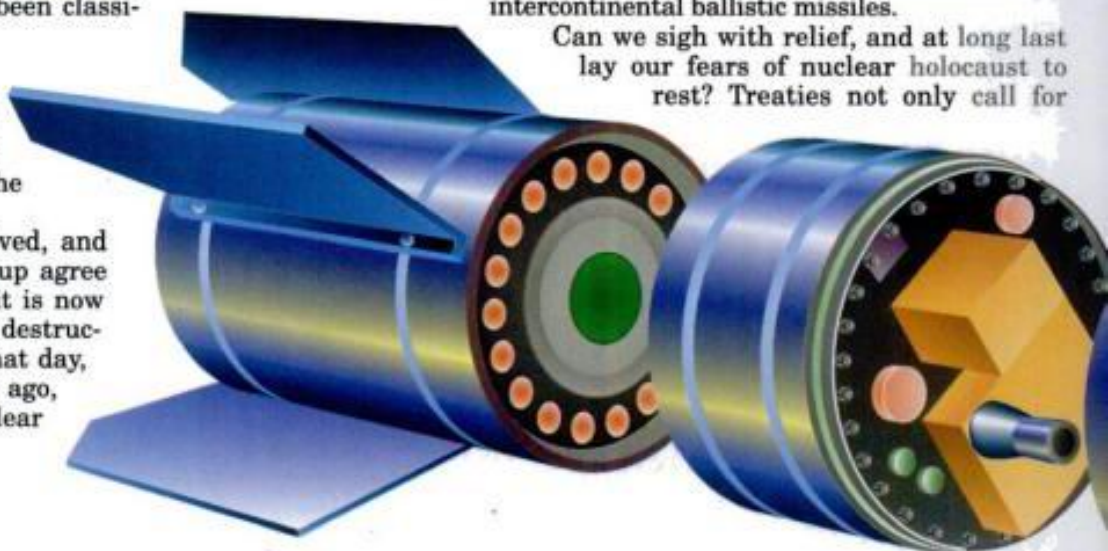
In January, Pantex officials allowed **POPULAR SCIENCE** inside the complex's razor-wire fences for an unprecedented tour. Building 104, a new \$30 million structure officially known as the Weapons Special Purpose Bay Replacement Complex, was still undergoing safety tests and had not yet been classified. Since our visit, it has gone "behind the fence," according to Tom W. Walton, public affairs officer at Pantex. It is here that the next chapter in the epilogue of the Cold War is being written.

The Soviet Union is dissolved, and the nations born of its breakup agree with the United States that it is now time to reduce the stockpile of destructive energy stored up since that day, a little more than 50 years ago, when the first controlled nuclear

chain reaction took place at Stagg Field on the University of Chicago campus.

Just a few years ago, the United States and the Soviet Union had a total of about 50,000 nuclear weapons in their stockpiles. Some of these weapons have already been dismantled. The Strategic Arms Reduction Treaty (START) calls for cutting the nuclear warhead count from around 9,000 per side to 6,000 per side. START II—designed to eliminate multiple-warhead, land-based missiles—would further reduce the strategic-weapons arsenals to 3,500 per side. The United States has already withdrawn all short-range and naval nuclear weapons formerly stored abroad, and the Russians say they no longer target the United States with intercontinental ballistic missiles.

Can we sigh with relief, and at long last lay our fears of nuclear holocaust to rest? Treaties not only call for



**Popular
Science**

APRIL 1993

TAKING APART

A B-61 nuclear bomb (rear) is broken down into four major subassemblies (center), which are dismantled separately. The bomb has about 6,000 parts, some of which are displayed on this table.



SANDIA NATIONAL LABORATORIES

THE

the dismantling of warheads, but also for the destruction of missiles and other delivery systems. And the production plants for fissionable materials—the plutonium and uranium that power nuclear weapons—stand idle. But despite all these changes, no government has any plans to destroy or make totally inaccessible its inventory of fissionable materials. Nuclear firepower is not going out of existence—merely into storage.

The atomic bomb was developed by the United States in the fear that Nazi Germany's scientists would be first to implement a concept known to all physicists since the 1930s—nuclear fission. That concept inflated physics, once a concern only of theoreticians and tabletop experimenters, into a huge industry and a major instrument of national power. Despite Germany's defeat in the spring of 1945, the bomb program hastened to its conclusion: Two atomic bombs were dropped on Japan in August of that same year.

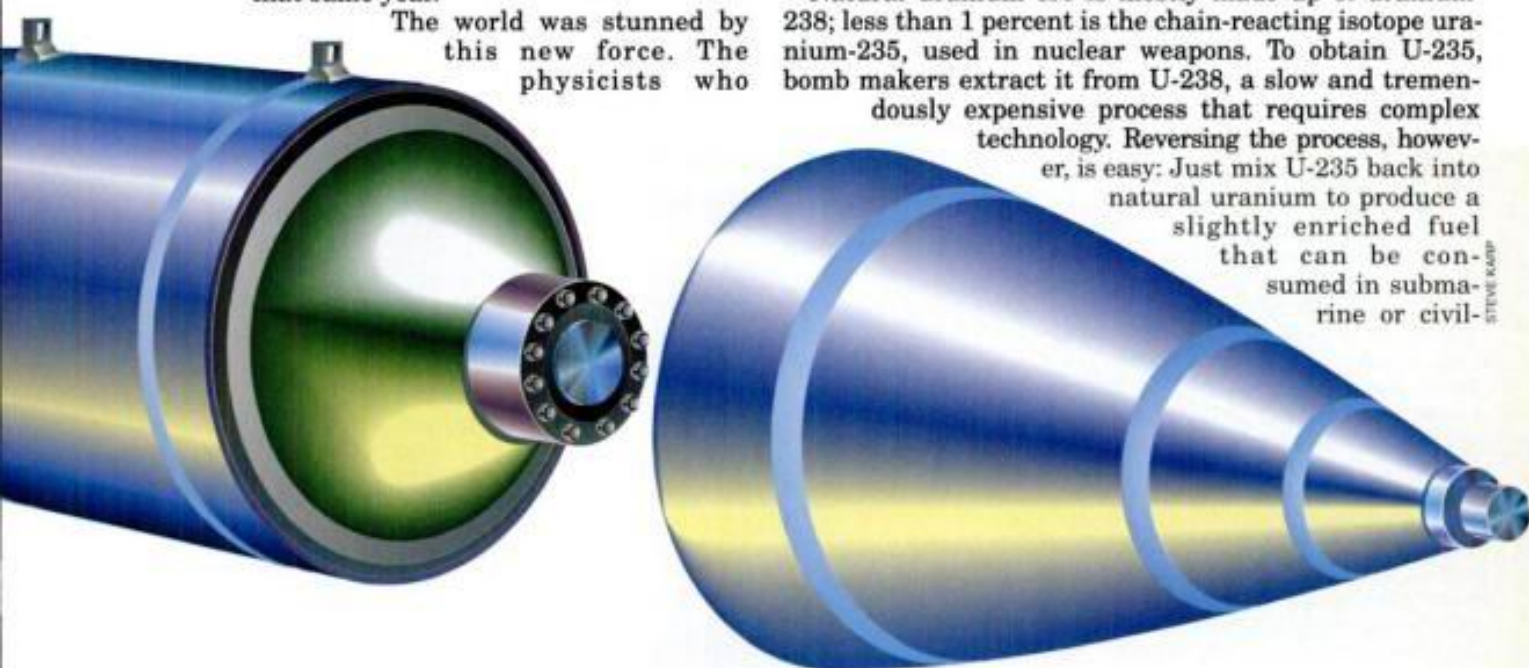
The world was stunned by this new force. The physicists who

had created it foresaw the future—that the Soviets would have the bomb soon (they did, by 1949) and that an arms race would follow. Now that race has finally ended, and the competitors—who together spent more than a trillion dollars to create their nuclear weapons complexes—are making plans for the dismantling of their arsenals. This is a positive step, but not one that will soon bring an end to the mess caused by nuclear weapons. In their race to produce weapons, the cold-warring nations contaminated land, air, and water with radioactive materials and toxic chemicals. As much as 15 percent of the former Soviet Union's territory is now estimated to be unfit for human habitation. In the United States, the cleanup is expected to take decades and will cost at least \$200 billion. Weapons dismantling in the next few years will add to this legacy an estimated 25 tons of highly enriched uranium and ten tons of plutonium.

Natural uranium ore is mostly made up of uranium-238; less than 1 percent is the chain-reacting isotope uranium-235, used in nuclear weapons. To obtain U-235, bomb makers extract it from U-238, a slow and tremendously expensive process that requires complex technology. Reversing the process, however,

is easy: Just mix U-235 back into natural uranium to produce a slightly enriched fuel that can be consumed in submarine or civil-

STEVE KARP



BOMB

**Disassembling
a nuclear
weapon is easy.
The hard part:
Getting rid of
its radioactive
innards.**

BY KEVIN CAMERON

THE INSIDE STORY OF PANTEX: THE UNITED STATES'

SPECIAL DELIVERY

Weapons arrive at Pantex in armored, guarded trucks known as Safe Secure Tractor-trailers, or SSTs. Radio and satellite equipment enables government officials to track trucks' whereabouts at all times.



JOHN B. CARVETT

Pantex was once responsible for assembling weapons, but its more important mission now is disassembly. Employees work on about four nuclear weapons types in a year, out of about 30 in the U.S. arsenal. During the past 40-plus years, the Department of Energy has disassembled close to 50,000 weapons. Not all of the weapons, however, have been retired. Some were taken apart for testing, and were then reassembled. Others were retrofitted to create new weapons.

Weapons arrive at Pantex in armored, guarded trucks and are stored in bunkers (see illustrations at right). The weapons are inspected, separated into subassemblies, and finally broken down into individual parts for recycling or disposal. Workers separate the chemical explosives and radioactive materials, then store the weapons' plutonium pits.

Pantex has the capacity to disassemble about 2,000 weapons per year. But at that rate, the plant will soon run out of storage space for plutonium pits, which are no longer sent away to be made into new bomb cores. Proposals now on the table would allow Pantex to expand the storage space for pits, which would remain at the plant for an "interim" period of six to ten years. After that, the pits could be moved to another storage site.—Dawn Stover

IAN WOODFORD

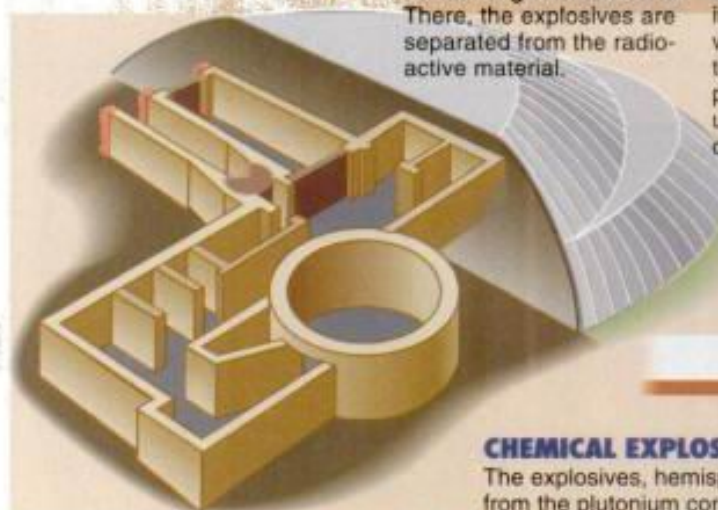


DISASSEMBLY CELL

If it contains sensitive chemical explosives, the portion of the weapon containing radioactive material goes to a "cell" buried beneath more than 15 feet of gravel and sand. There, the explosives are separated from the radioactive material.

SPARE PARTS

A weapon such as the B-61 bomb is broken down into its subassemblies, which are further reduced to thousands of individual parts. Parts that are not re-used or recycled are crushed beyond recognition.



CHEMICAL EXPLOSIVES

The explosives, hemispherical shells cut away from the plutonium core, are burned outdoors.



ian power reactors. Without the extraction technology, the mixture is useless for bomb production.

Plutonium, however, is a problem. Nonexistent in nature, plutonium is created in nuclear reactors by irradiating natural uranium with neutrons. Unlike U-235, plutonium can be chemically extracted from any mixture with ease.

Arms control experts believe plutonium is relatively safe in fixed storage at military bases or dismantlement centers. The cost of such storage is estimated at \$1 to \$2 per gram, or between \$300 million and \$600 million per year worldwide—not too much to pay for protection against the unauthorized use of this dangerous, cancer-causing material.

Greater risk occurs in transit. A special armored "white train" was once used to convey U.S. nuclear weapons to Pantex, the nation's only dismantlement center. Now a fleet of 70 special armored trucks, escorted by heavily armed guards, transports weapons to the 16,000-acre plant, located east of Amarillo, Texas.

The bombs, warheads, and artillery shells that the trucks transport to Pantex are delivered to an area called Zone 4 and temporarily stored in "igloos," bunkers made of reinforced concrete covered with at least three feet of soil. From the igloos, weapons are moved to buildings that are designed for inspection, assembly, and disassembly tasks. Building 104, one such facility, contains eight

NUCLEAR WEAPONS DISMANTLEMENT CENTER

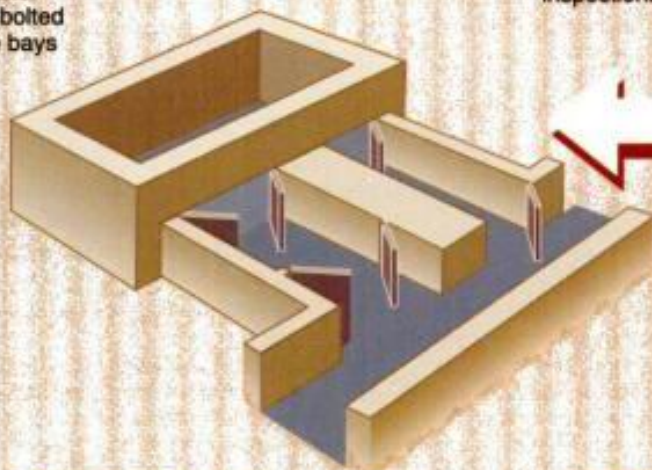
WEAPONS STORAGE

The weapons are temporarily stored in dirt-covered concrete bunkers called "igloos." A giant forklift moves 5,000-pound concrete blocks away from the igloo doors to permit access.



DISASSEMBLY BAY

Technicians take apart weapons in "bays," which have thick, heavy walls and doors. The inner doors cannot be opened until the outer doors are closed. Weapons, bolted to carriers, are rolled into the bays through the larger doors.



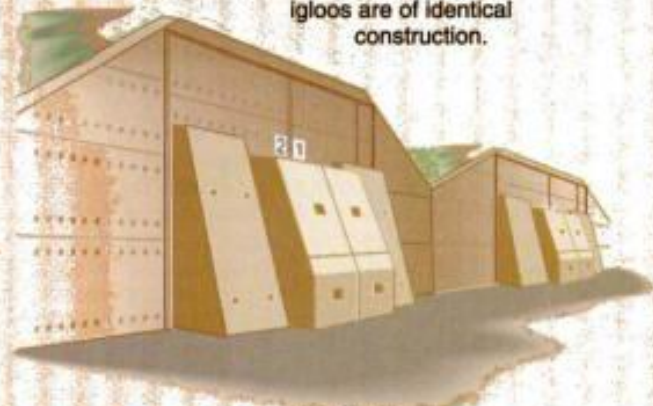
X-RAY INSPECTION

Before they are disassembled, many weapons go to a radiography bay for high-power X-ray inspections.



PLUTONIUM STORAGE

The steel container goes to an igloo for "interim" storage. Plutonium and weapons are stored in separate igloos, but the igloos are of identical construction.



PLUTONIUM PIT

The bomb's core—a plutonium pit covered with a protective jacket of metal—is placed in a metal holder, which is stored inside an insulated steel container.



"bays"—large, heavily shielded rooms. The walls consist of 15 feet of earth sandwiched between a pair of two-foot-thick layers of concrete, and the entrances are protected by 1,100-pound doors. The floors are made from paint chips that are mixed with polyurethane to form a spongy material deemed unlikely to set off explosives. While there is little danger of a nuclear detonation, it's possible that the chemical explosive of a weapon could blow up during the disassembly process. If that were to happen, the room's shielding would help contain the blast.

In one of the bays, technicians operate a powerful X-ray machine that can penetrate 15 inches of steel. "You want to know what the weapon system's condition is before you

dismantle it," explains Randall L. Hodges, production supervisor for nondestructive evaluation.

Technicians place a weapon on a large turntable. Film is attached to a screen behind the turntable; pointed at the weapon is a linear accelerator suspended from a gantry—a jumbo version of the X-ray machine your dentist points at your cheek. A computer automatically controls the movement of the turntable and linear accelerator, and the technicians can watch the X-ray image as it's being made. Then they can add false-color enhancement to detect flaws.

After the X-ray inspection, the weapon goes to an assembly/disassembly bay. "You use essentially the same

[MEDICAL DISCOVERIES] CONTINUED

recently helped to conduct a large-scale study involving nearly 700 Danish children. Some intriguing correlations emerged. Scouring for trends among a host of parameters such as birth weight and socioeconomic status, scientists discovered an increased prevalence of autism both in children with a family history of schizophrenia and in those whose births involved complications such as premature or breech delivery.

Casting an even wider net than the Danish survey, researchers at the University of California at Davis are conducting a study called CHARGE (Childhood Autism Risks from Genetics and the Environment) to scrutinize everything from

The only other disease that rivals autism in complexity is cancer, says Pessah.

genes to mercury exposure. "The hope is that we'll find patterns," says toxicologist Isaac Pessah, who is director of the school's Center for Children's Environmental Health. "We're not looking for the magic bullet that causes autism."

Churning through reams of data, the study has uncovered its first pattern: that certain proteins, metabolites and immune-system components in blood samples from autistic children differ sharply from normal ones. Announced in May at the International Meeting for Autism Research in Boston, the discovery could lead to the first-ever blood test for autism in newborns, allowing treatment to begin long before outward symptoms typically occur.

If autism is indeed caused by the complex interaction of genetic and external factors, Pessah believes that eliminating the environmental problems would be easier in the short term than the awesome biomolecular challenge of finding and altering the offending DNA. "I don't think there's going to be genetic intervention in my lifetime," he says. There is only one other human disease, Pessah points out, that rivals autism in complexity. It's called cancer. —JOSHUA TOMPKINS

[WEAPONS]

Bombs Away?

Scientists cast doubt over the Pentagon's plan to build a new nuclear bunker buster

ACCORDING TO THE U.S. DEPARTMENT OF DEFENSE, HUNDREDS OF underground bunkers in enemy territories serve as weapons silos, command centers and safe havens for rogue leaders. Drilled several hundred feet or deeper into the ground, many of the hideouts are far beyond the reach of conventional weapons. The Pentagon's solution: Build a super-slim bomb called a Robust Nuclear Earth Penetrator (RNEP) capable of piercing 20 feet of solid rock and unleashing shock waves on par with a magnitude-7 earthquake.

This fall Congress will decide whether to approve \$8.5 million to complete a feasibility study of the RNEP. But a recent report from the National Academy of Sciences, a government-funded scientific advisory group, threatens to strike the weapon dead. Issued in May, the 150-page report concludes that the "bunker buster" would fare better than conventional weapons but may leave many targets unscathed and could result in more than one million civilian casualties.

On all counts, an earth-tunneling bomb is a tall order. The sole nuclear bunker buster in the U.S. arsenal, the 300-kiloton B61, can't penetrate rock. According to the NAS, to strike deeply buried targets in rocky terrain would require a one-megaton bomb or stronger—one that is up to 80 times as potent as the Hiroshima bomb. What's more, the RNEP would need to burrow thousands of feet into the ground to contain fallout from the blast.

Here, one scenario envisioned by the NAS. —RENA MARIE PACELLA



THE B83 MAKEOVER

The Pentagon plans to convert its B83 thermonuclear gravity bomb into a nuclear bunker buster in large part because the Nuclear Non-Proliferation Treaty of 1970 discourages the building of new nukes. With a 1.2-megaton yield, the B83 is our nation's largest warhead. It would be retrofitted with a sharpened nose for spearing rock and a shock-mitigating layer to protect it on impact.

B-2 BOMBER

NUKING A BUNKER, IN FOUR STEPS

1 A B-2 bomber flying at an altitude of 40,000 feet drops a modified B83 nuclear weapon carrying a 1.2-megaton warhead. It travels 2,000 feet per second toward its ground target.

2 Assuming the soil is composed of granite, the nuke will penetrate to a depth of 20 feet within 100 milliseconds. Radar sensors on the warhead detonate the nuke once it has plowed to its target depth, releasing the energy of more than a million tons of TNT.

3 The blast creates a 1,200-foot-wide crater and sends a shock wave traveling 1,116 feet per second through the ground. The wave will destroy everything down to 1,000 feet. Any bunkers deeper than that could survive the blast.

4 The National Academy of Sciences estimates that the explosion will shoot some 300,000 tons of radioactive debris up to 15 miles into the air. The total number of casualties will vary but could exceed one million, depending on weather, wind velocity and the blast's proximity to towns and cities.

AN ILL WIND BLOWS

Where and how far radioactive debris travels depends on weather and wind conditions. On an average day in North Korea, radiation from a 1.2-megaton blast could reach as far as Tokyo.



FOUR-DAY RADIATION EXPOSURES

YELLOW Lethal to 50 percent of population

ORANGE Induces radiation sickness

RED Equivalent to a full-body x-ray

Source: Federation of American Scientists

1,000 feet

SPY ANATOMY

The USS *Jimmy Carter* is one of the Navy's three Seawolf-class subs—the largest, fastest and most heavily armed in the fleet—with a billion dollars' worth of modifications tacked on. Most of these, such as new launching systems for pilotless aircraft, a super-stealthy jet-propeller design and the first-ever "wasp waist," will help the craft carry out its primary mission: espionage.

SUPER SONAR

You may not hear the *Carter*, but with the help of a 30-foot golfball-like array of microphones mounted in the bow, it can hear you. Other arrays mounted in the ship's sides will help the *Carter* quickly triangulate the source of a sound.

Capsule launcher

LAUNCHING AERIAL

The masts on a sub's sophisticated video cameras, but they can't see the horizon. Solution: single-use unmanned aerial vehicle (UAV), packed in a capsule with wings folded, from a capsule in the wasp waist. As the capsule rises to the surface, it launches the UAV with a built-in catapult.

Microphone array

Missile launch tubes

CARTER AT A GLANCE

Size 453 by 40 feet

Weight 12,190 tons

Power plant General Electric S6W nuclear reactor that powers dual steam turbines

Cruising speed 35 knots (est.)

Max. depth 2,000 feet (est.)

Crew 140

Cost \$3.2 billion

Namesake The only U.S. president to have been a submariner

Torpedo tubes

INTERNET AT SEA

Cold War submarines used to be silent, seldom transmitting except in an emergency, but silence doesn't work when a mission requires the submarine's time-sensitive intelligence. The Carter's miniature satellite-communication antennas can pump beams of data to spacecraft overhead yet are small enough to fit on the top of the submarine's extending masts. The sub can also trail an antenna hundreds of feet behind it so as to better hide its true position.

AL SPIES

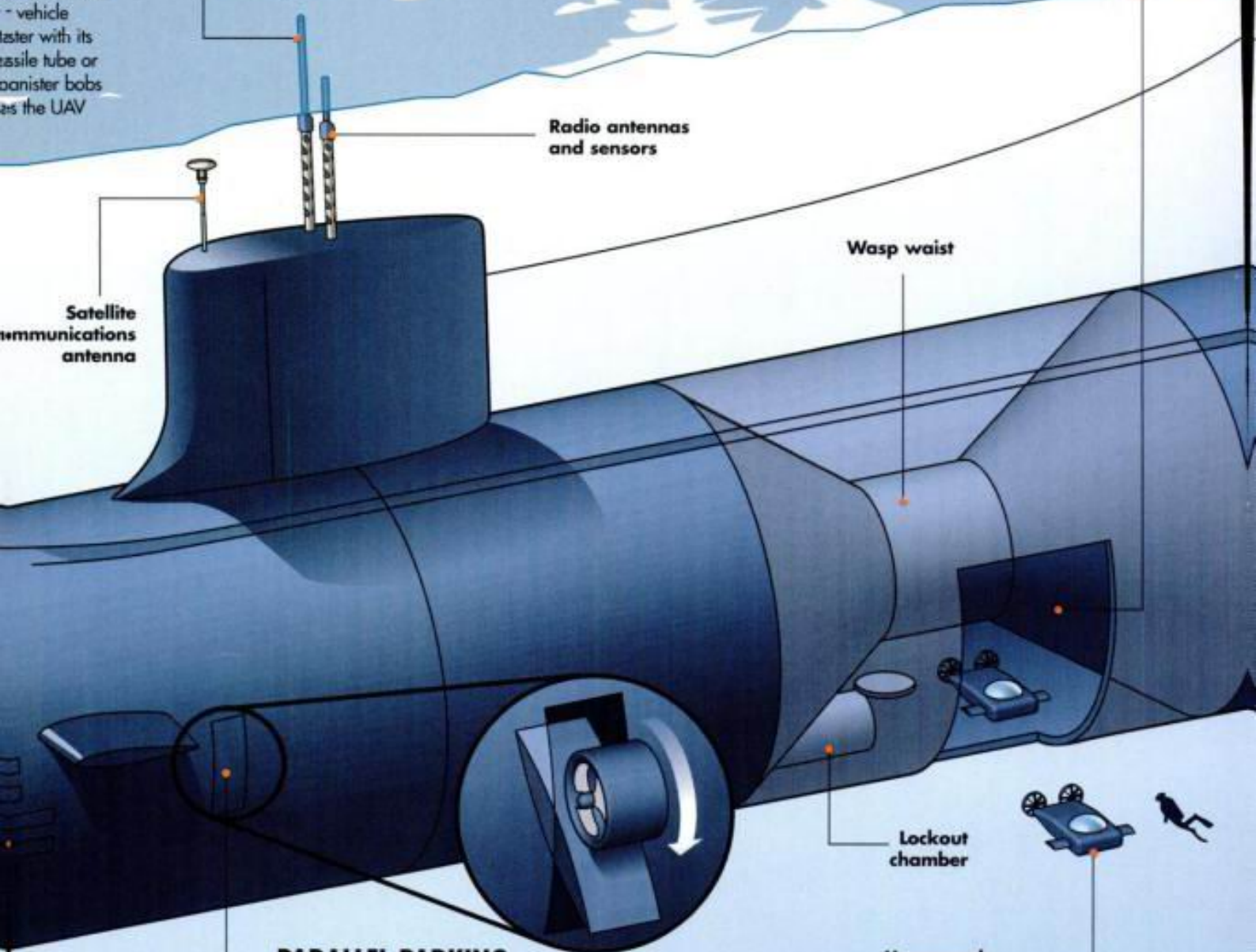
I carry
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Towed satellite ante

UNDERWATER GARAGE DOOR

Just behind the mast, the Carter's watertight pressure hull shrinks to a narrow walkway. The space between this tunnel and the smooth outer hull fills with water, and big sliding hatches open the space to the ocean. This unique "wasp waist" section lets the crew launch and recover objects that are larger than a standard 21-inch torpedo tube using a lockout chamber to connect the boat's interior to open water.

The Navy isn't saying exactly how it will be used, but payloads are likely to include unmanned underwater vehicles and Seal raiding craft.

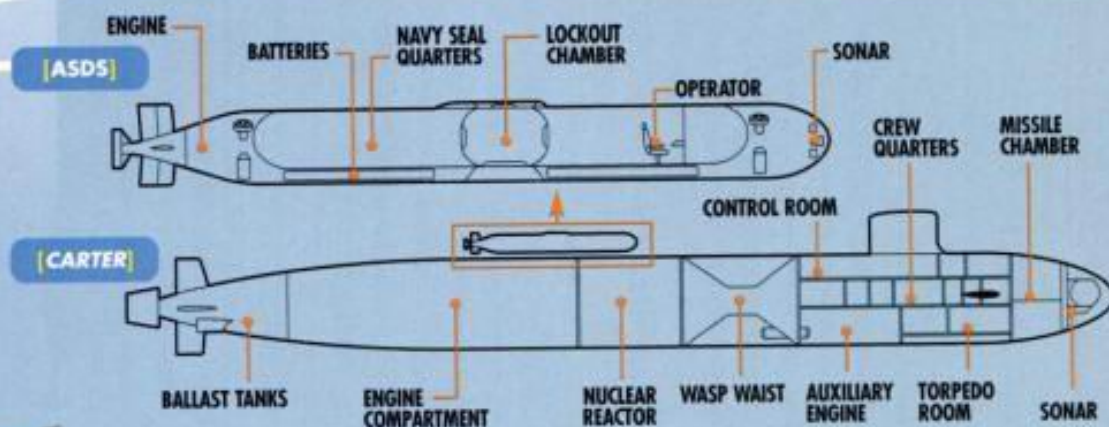


PARALLEL PARKING

Four electric, ducted propellers pop out of recesses in the Carter's hull to maneuver the submarine at speeds down to one tenth of a knot. Powerful and quiet, with their motors built into their impeller rims, the maneuvering propellers can even spin the massive boat around its own axis.

Inside the Ships

The Carter shares its basic layout with Seawolf-class subs, with the 100-foot-long wasp waist added during its four-year renovation. The ASDS is the first mini sub to include a lockout chamber to keep Navy SEALs dry.



ASDS mini sub

Auxiliary propeller housing

SPECIAL FORCES

Navy Seal teams w water in a battery- the Advanced Seal ASDS. Unlike older filled with water be sure hull, the ASDS that keeps up to eig vents the fatigue co ing through scuba semi-truck-size ASD when it comes to s thrusters for ultrap runs for up to 48

Navy Seal divers

Anchor

HOW TO SPY FROM A SUBMARINE

The Carter's myriad innovations will be used for highly specific combat functions. The ASDS mini sub it carries will be able to maneuver undetected into enemy ports, releasing its cargo of Navy SEALs onto a boatyard or shore. The Carter's encapsulated unmanned air vehicles will be able to investigate enemy targets out of range of conventional UAV launches. And its UAVs will be able to perform reconnaissance in spaces submarines can't reach. But perhaps its most intriguing ability—and certainly its most secret—will involve tapping the undersea fiber-optic cables that carry most of the world's data. Although the Navy and the National Security Agency are keeping mum about their ability to tap the cables, the Carter's auxiliary propulsors will be able to hold the sub in place over a specific spot on the ocean floor, and the wasp waist can launch small manned vehicles designed for just that purpose.

SILENT RUNNER

Submarines survive by stealth, and nothing can make as much noise as 52,000 horsepower delivered through the propeller. That's why the details of propeller technology are a closely guarded secret. Photos show, however, that the Carter has been fitted with a British-developed pumpjet. It works by limiting cavitation—the formation and collapse of bubbles in the wake of the spinning blades, and the main source of propeller noise.

MINI SUB

venture into shallow red mini sub called very System, or subs that completely they lacked a pres-a lockout chamber ivers dry. This pre-by hours of breath-in frigid water. The mini" is relative nes) uses fold-out maneuvering and at a time.

Pumpjet propulsor

Propeller

Anti-swirl vanes

Duct wall

Static struts

PUMPJET AT WORK

In a pumpjet, any bubbles formed by the propeller are trapped against the outer duct wall. Then the anti-swirl vanes at the duct exit both remove the natural twist from the rushing water and implode any residual bubbles.

POPSCI See photos of the
ON THE WEB USS Jimmy Carter
cruising at sea at popsci.com/carter.

A Scientist Previews The First Atomic Airplane

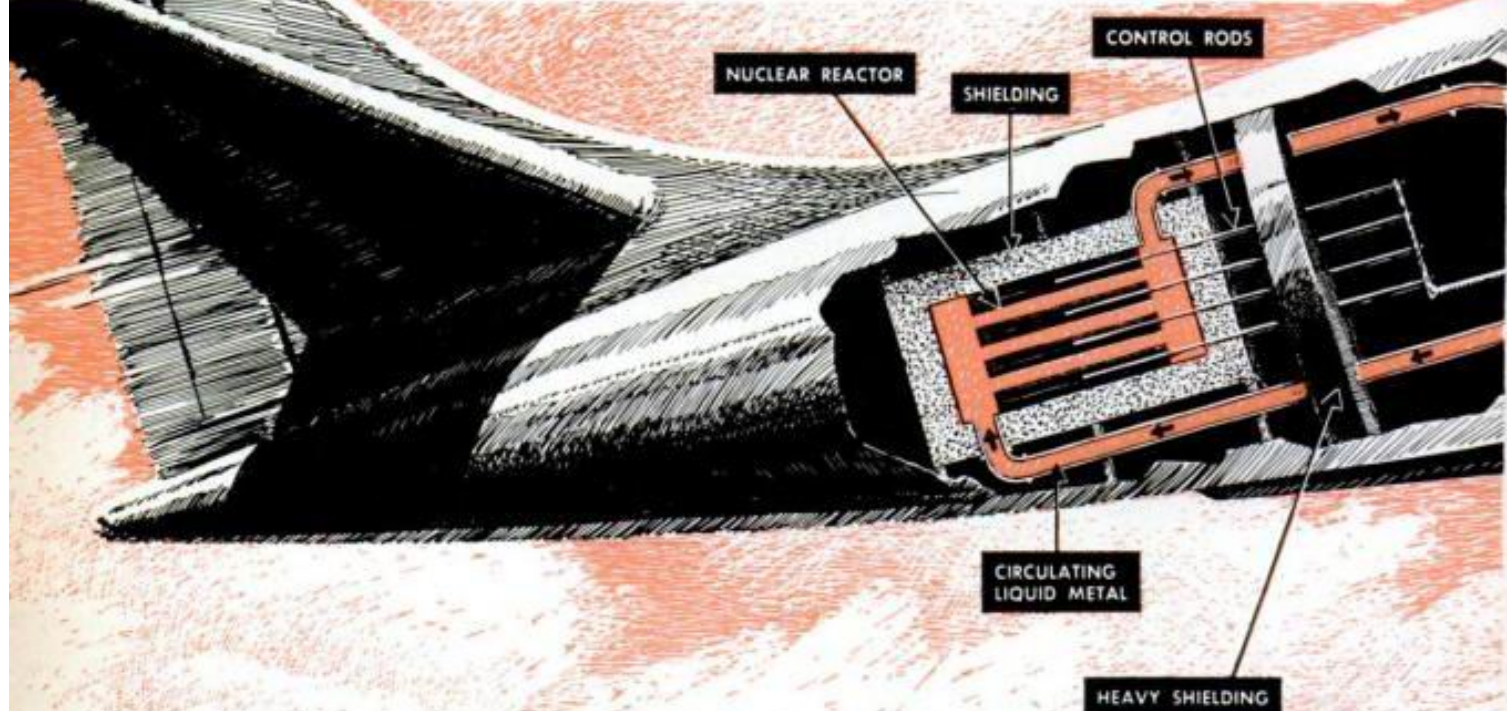
A new era in aviation approaches as official reports hint nuclear power for flying is closer than you think.

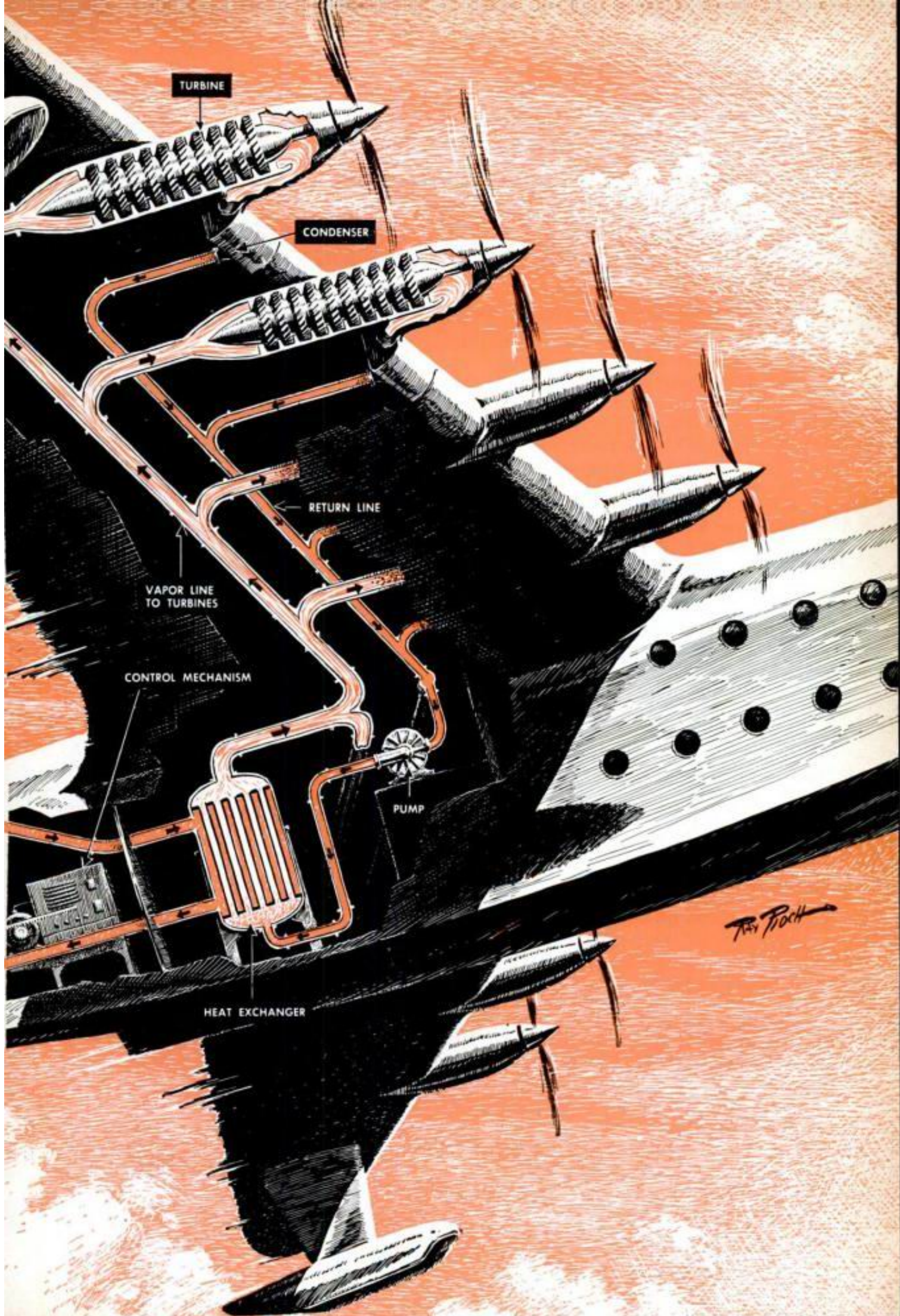
By Gerald Wendt

Author of "Atomic Energy and the Hydrogen Bomb"

THE first atomic-powered plane—already being designed—will be a big plane, probably a flying boat. It will have wide but thin wings to combine lift with high speed. It will have no fuel tanks, yet will be able to stay afloat almost indefinitely. It will run on steam. Its power plant will look a good deal like a yacht's, with a red-hot boiler and turbine engines geared to propellers.

Such a power plant can be built now. A long-range plane that





can go to the other side of the earth and back again, or all the way around, without refueling, is needed now. And the time when atomic power will be used to extend the range of aircraft tremendously is drawing closer. A carefully worded report by the U. S. Atomic Energy Commission on progress in the first six months of 1951 makes this terse but significant announcement: "Development of reactors to propel military aircraft also advanced."

Squeezing a Pile in a Plane

Yet the first atom plane is unlikely to be either a long-range bomber or a transport plane. Instead, it will be a flying laboratory for the armed services. The power plant probably will be so heavy that it will use up all the weight—up to 50 tons—saved by omitting fuel. Thus the great advantage of atomic power, the increase in payload made possible by the almost weightless atomic fuel, will be sacrificed. Still, the plane will have unlimited range, a big step ahead.

Eventually, perhaps within 20 years, this plane will be followed by atomic jets, ram-jets and even rockets. Nuclear reactors will be developed that can pour their vast energy directly into compressors, heating airstreams to such a flame temperature that they will have the thrust of a jet. But not yet. Not enough is known now about reactors at white heat, nor about the ability of air to wipe that heat off instantaneously at jet speed, nor about metals that can stand both the high temperature and the intense radiation.

Until such problems are solved, the re-

actor used in a plane must operate at relatively low temperature. It will pass its heat to a circulating liquid metal that will in turn pass the heat on to a heat-exchange unit. There a working fluid—mercury or water—will be vaporized to drive a turbine. Then the working fluid will be cooled in a condenser and pumped back to the heat exchanger. All this adds up to plenty of weight.

The reactor itself need not be big. Half an ounce of fissionable uranium (the kind that splits) or plutonium can furnish as much energy as the entire 17,000 gallons of fuel carried by the B-47 Stratojet. Less than a pound would be used up in a 50-hour flight around the globe. But neither fissionable uranium nor plutonium can be used in pure form.

The bulk of the first reactor put into an airplane probably will be ordinary, non-fissionable uranium. This will be enriched with fissionable uranium 235 to permit the chain reaction. Graphite blocks or some other "moderator" will be needed, too, to slow down the fast neutrons and keep the "fire" burning. The generation of power may be controlled by cadmium rods, pulled out of the reactor when power and speed are wanted, pushed in to absorb the neutrons and "bank the fire" for slowed-down flight or landing. So the reactor alone will probably account for several hundred pounds.

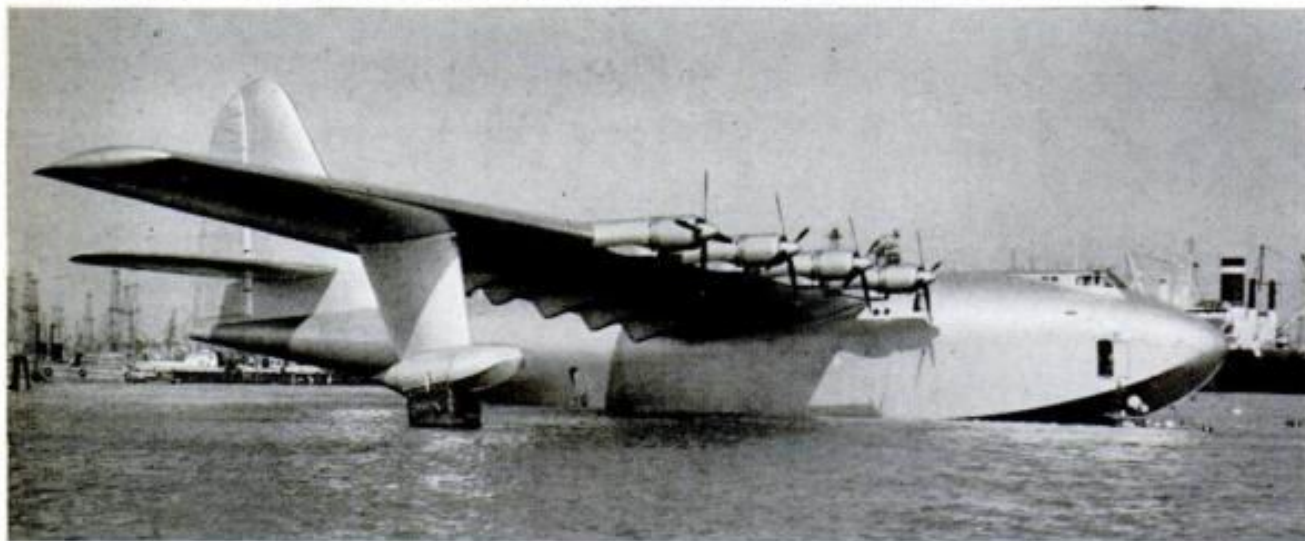
Must Protect Crew

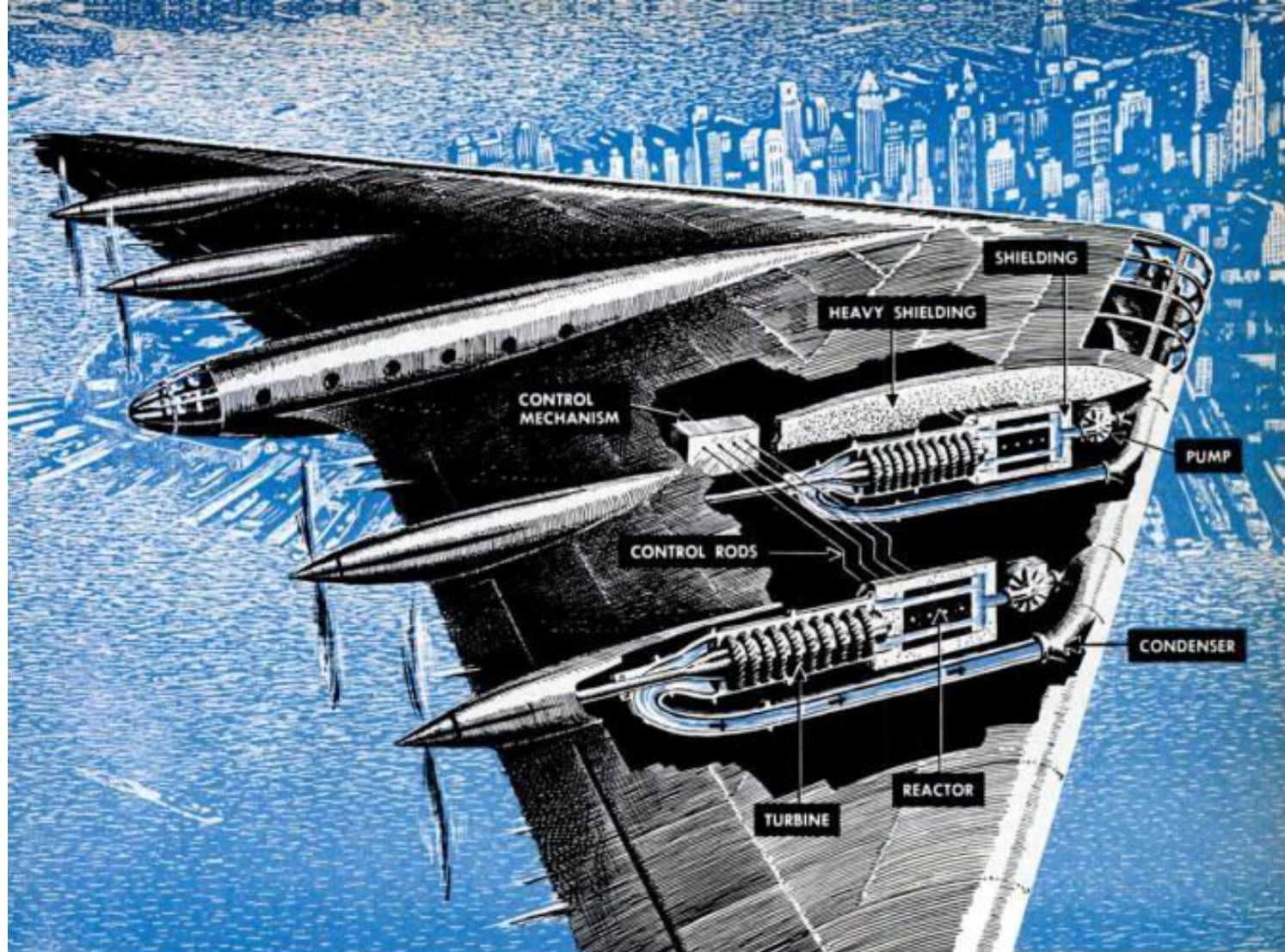
But the reactor only provides the heat. Transmitting the heat to the turbines will involve more equipment—and more weight.

It will not be possible to take the heat

Big flying boat is best bet for first atomic aircraft because of great size and long take-off run needed to lift heavily shielded reactor. It

might be similar to world's largest plane, below, Howard Hughes' 219-ft. Hercules, which has four engines in each 160-ft. wing.





Future model could be a flying wing with separate reactor coupled directly to each turbine.

Its design awaits development of materials able to withstand high heat and radiation.

from a reactor of the type now in use directly into the working fluid of turbines because of the enormous neutron and gamma-ray activity within the reactor. The working fluid which circulates through the plane to the engines in the wings must be protected from that bombardment or it will become radioactive and endanger the crew. But a heat-transfer fluid can be interposed, probably a low-melting alloy of sodium and potassium. This would circulate through the reactor to pick up the heat and deliver it to a heat exchanger where it, in turn, would heat the actual fluid used to operate the turbines.

Shielding Adds Weight

A reactor and heat exchanger of this type would be "hot" with radiation as well as in temperature, but might not pass the radioactivity on to the working fluid. Still, they would have to be encased in heavy and bulky shielding—probably lead—to stop the radiations from penetrating the plane.

From the heat exchanger in the shielded section, high-pressure vapor lines might

carry the steam to six or eight turbines—one for each propeller—mounted in nacelles in the wings.

There the energy of atomic fission would be finally delivered and converted into motion. No shielding would be necessary, but the loss of temperature and pressure through the long lines would be a disadvantage.

This loss can be eliminated only when it becomes possible to provide each turbine with its own reactor, mounted alongside it in the wing.

Atomic Warm-Up Takes Time

There also are other problems. The molten metal used as the primary heat-exchange liquid would solidify as it cooled when the reactor was shut down. The first step in bringing the plane to life would be to liquefy the metal with auxiliary heat, probably from a small gas turbine. Furthermore the metal would not be allowed to solidify throughout the system, but would have to be drained from the reactor, the heat exchanger and piping. In fact, the whole system would have to be purged of the liquid

nades still belongs in the realm of science fiction.

- Smaller atomic explosions, less than the equivalent of 20,000 tons of TNT, have been produced. But detonations must still be measured in terms of thousands of tons of TNT.

- Making the bomb smaller involves a definite loss in efficiency or in the percentage burn-up of uranium in the bomb. A very small bomb for firing in an artillery piece is not as efficient as a larger bomb dropped from an airplane.

The atomic howitzer weighs 85 tons. Its dinosaur proportions make it a stand-out target for enemy counteraction. However, it can project a shell more than 15 miles with quite high accuracy. This will

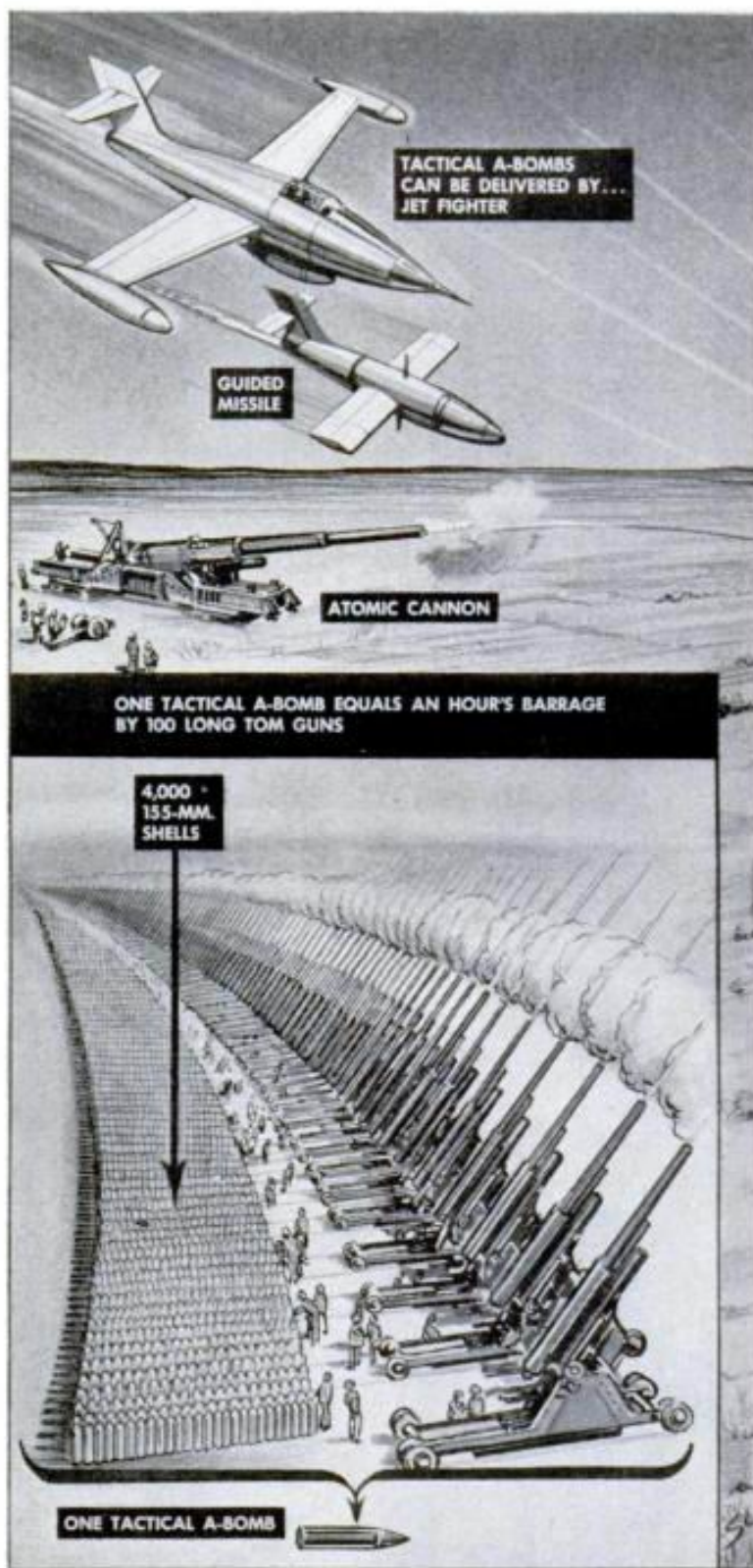
THE AUTHOR of this article was a division director of the famous Manhattan project that built the first atom bomb. After the war he held a series of posts concerned with scientific research for the armed forces. At present he is in private business as an industrial consultant. This article is condensed from a chapter of his latest book, *The New Force*, copyright 1953, by Ralph Eugene Lapp (Harper, \$3). The drawings at right illustrate Dr. Lapp's conclusions.

be of value against massive concrete fortifications where pinpoint accuracy may be needed even with A-shells.

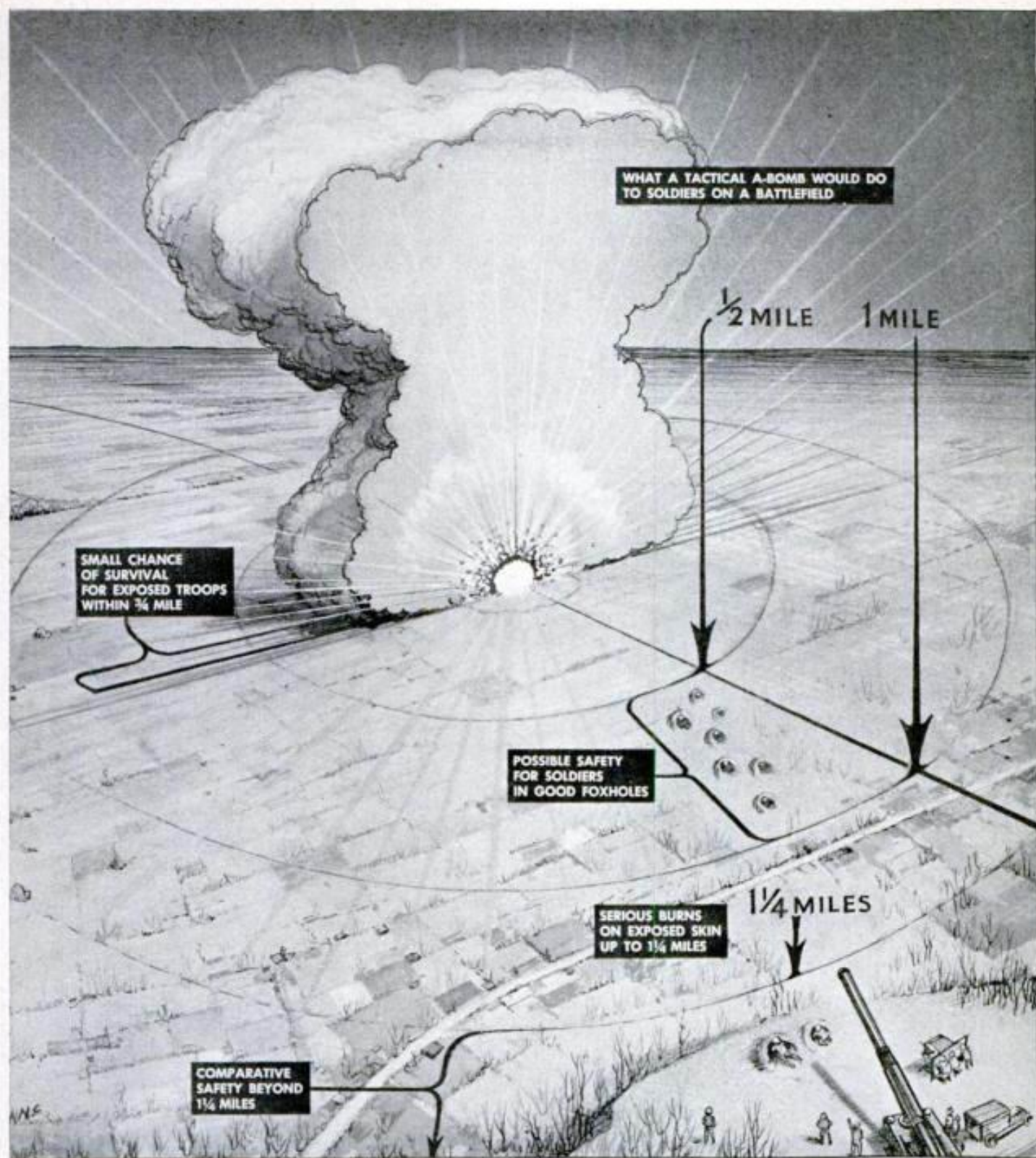
Deadly Action Covers Big Area

The A-gun can fire in any kind of weather when aircraft might be grounded and be unable to deliver the required A-weapon. Its accuracy is important because the large radius of lethal action of the A-explosive might overlap friendly troop positions if good accuracy in delivery were not achieved. Finally, the A-gun can be used even if the enemy has command of the air. Air Force officers dispute the latter claim since they feel that the A-gun is an easy target for enemy aircraft.

Although A-weapons for tactical use come in assorted sizes, it is useful for purposes of discussing the effect of the



weapon on the battlefield to fix attention upon a 10 kiloton bomb. That is one which is equivalent to 10,000 tons of TNT or is one half as powerful as the Nagasaki bomb. Specifying just what damage a 10 kt. A-bomb explosion will do on the battlefield is much more difficult than predicting what the same explosion would do against buildings.



As between people concentrated in a city and soldiers spread out on the battlefield it is clear that in general only the primary heat flash, the first flash of penetrating radiation, and the blast wave may be effective in causing battlefield casualties. Soldiers close in when the A-bomb explodes over them, say, within $\frac{1}{4}$ mile, will have a very small chance of survival

if they are standing up in the open—utterly unprotected. Beyond this distance an unprotected soldier would have increasing chance of escaping harm up to a distance of $1\frac{1}{4}$ miles where he would be safe, especially if he ducked and sought cover as he would be trained to do.

As a rule of thumb, anyone in a good foxhole at one mile from the burst would

Atomic Firepower vs. Artillery

**The A-gun can punch like 4,000 Long Toms,
but you still need a conventional army
to make the enemy give you an A-target.**

More tests of atomic weapons were being arranged at the Las Vegas (Nev.) Proving Ground as this issue of POPULAR SCIENCE MONTHLY went to press. Twenty nuclear devices were detonated there in 1951 and 1952. What is the significance of such tests to a commander and troops on a battlefield? How will atomic weapons strengthen them? The article which follows is a well-known atomic scientist's answer to these questions.

By Ralph E. Lapp

ESSENTIALLY, the Nevada tests are paving the way for a family of atomic weapons ranging from an aircraft bomb which can be used in tactical aircraft to one which could be fitted as a warhead to a guided missile. In this family of weapons the prototype of an atomic artillery shell has been tested.

Such tests have shown that:

- The size and weight of the A-bomb has been significantly reduced. But talk of baby A-bombs or atomic hand gre-



An Atomic Locomotive Could Be Built

Here's how a noted designer of reactors would construct it, provide shielding against the radioactivity of its power plant, refuel it—and revolutionize railroading.

A MIGHTY 7,000-hp. engine called the X-12, first atom-powered locomotive ever designed, is technically feasible. Within two years it could be hauling a high-speed Atomic Limited across country. Eleven pounds of uranium would fuel it for a year.

These are highlights of an atomic-locomotive study by a University of Utah group under the leadership of Dr. Lyle B. Borst, professor of physics and a former designer of nuclear reactors for the Atomic Energy Commission. Five railroads and nine industrial firms cooperated in the project, a private one having no connection with the AEC. Its conclusions are told in a remarkable 54-page report entitled, *An Atomic Locomotive: A Feasibility Study*.

Uranium Cost Is Secret

Because the study used only nonsecret data, nothing about it is censorable, and so the report is able to give the most revealing picture to date of the mechanical details of applying atomic power to vehicular propulsion.

For the same reason, the report necessarily lacks one secret figure—the exact cost of pure uranium-235 fuel—that is all-important in determining whether atomic choo-choos are the coming thing. But from what he considers a reasonable estimate, Dr. Borst predicts that “the

proposed locomotive will compete successfully with diesel power under favorable circumstances.”

Primarily, the object of the study was to learn whether an atomic locomotive could be built at all—a possibility doubted by many experts. The researchers believe they have a workable design.

Outwardly resembling a streamlined diesel, the projected “atom burner” is 160 feet long. It has two sections. The forward one, a power unit devoid of a smokestack, contains the nuclear reactor and its massive shielding. It also houses a steam turbine, electric generators, and electric traction motors to apply power to the 12 driving axles. In short, it is a turboelectric locomotive, whose steam boiler is built into and around the nuclear reactor itself.

The trailing section carries radiators equal to more than 1,000 automobile radiators, and its roof is studded with whirling fans. Its purpose is to cool the water circulated to it from the condenser of the steam turbine, and thus transfer excess heat from the atomic power plant to the surrounding atmosphere.

Fuel Will Be Liquid

Designers of this 360-ton rail giant visualize it at the head of a crack passenger train or a fast freight. The big advantage over conventional types that they

predict for an atomic locomotive—lower fuel cost—will show up best in hauling heavy loads at high speeds with short turnarounds.

The heart of the X-12, its six-sided nuclear reactor, is three feet square and one foot thick. It can be so small because it burns uranium of the concentrated U-235 variety. Its fuel will be in liquid form—a solution of uranyl sulfate, a yellow or yellow-green salt of uranium, in water.

When control rods are withdrawn from this liquid-fuel “soup,” a chain reaction takes place. Its heat vaporizes pure water in a surrounding jacket, the boiler that supplies steam to the locomotive’s turbine. The pure water circulates not only through the jacket, but also in 10,000 pencil-thin stainless-steel tubes extending through the soup in the reactor, to pick up heat more readily.

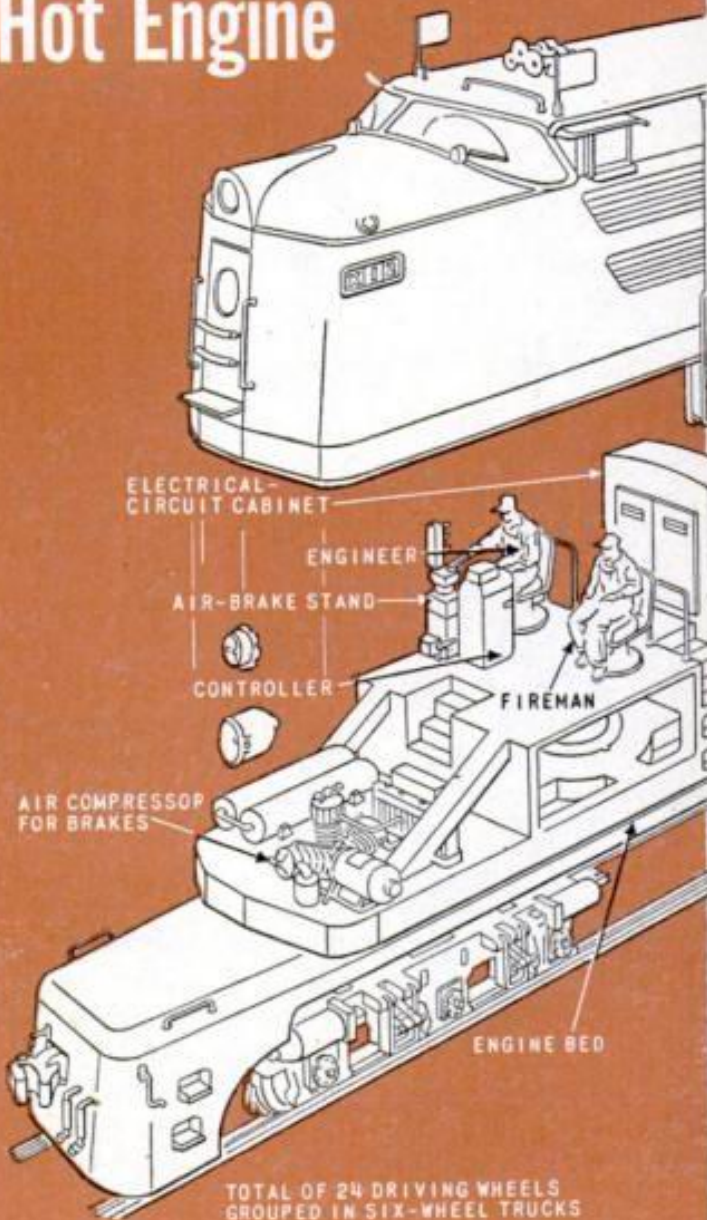
Once steam is up and the atom burner is rolling, its engineer’s task is a simple one. Principal instruments in his cab will be a conventional steam-pressure gauge and ammeter, and he will use a standard controller for a throttle.

Reactor Is “Infinite” Power Source

One outstanding feature of an atomic express, noticeable to engineer and passengers alike, will be its rapid pickup. The X-12 could be designed to accelerate a 5,000-ton train from a standing start to 60 m.p.h. in three minutes and 32 seconds. The reason is that, while its normal power is 7,000 hp., its reactor actually is an “infinite” or unlimited power source. So the engine could have an “overload capacity” of, say, up to 12,000 hp. for short periods.

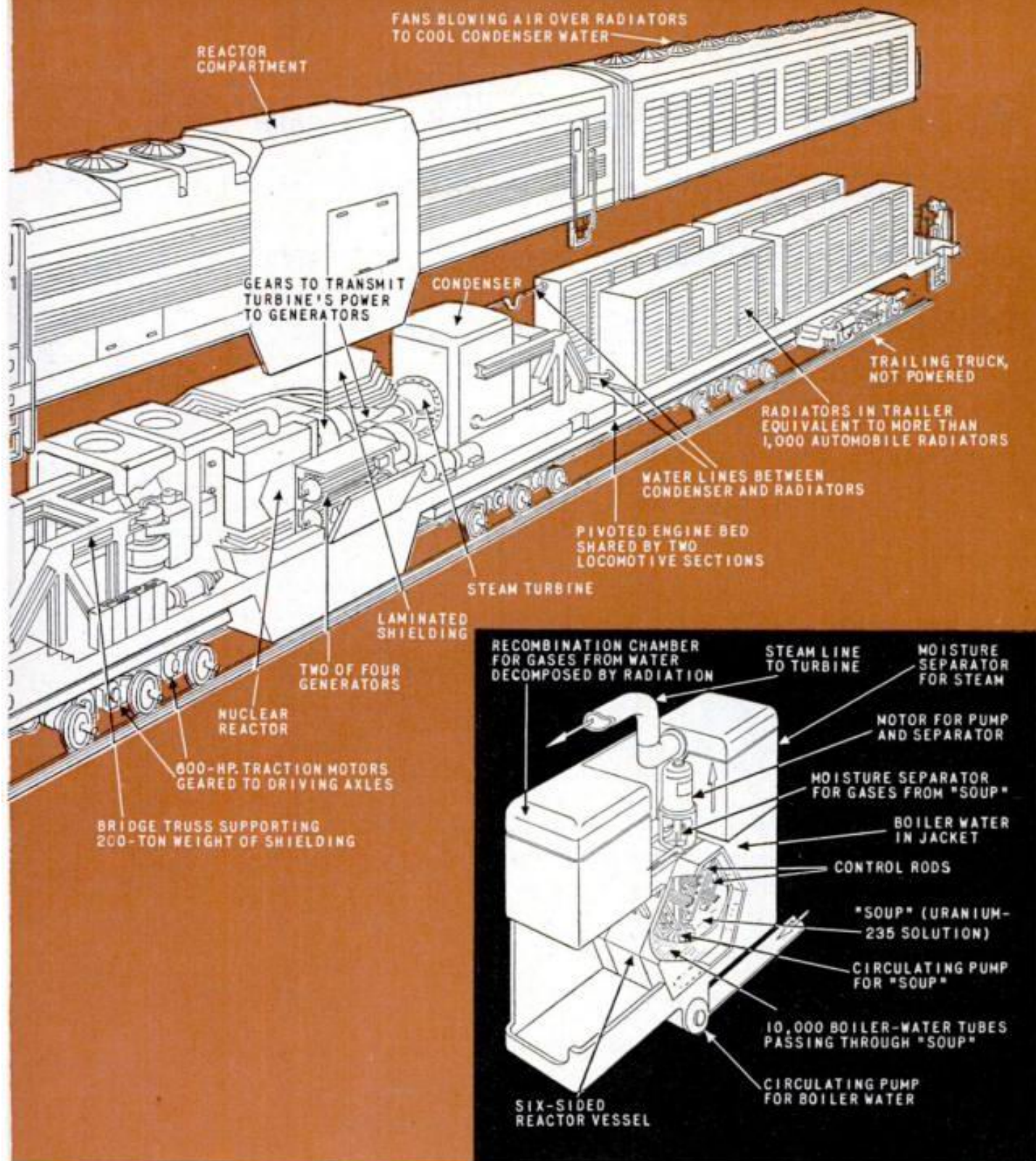
How can the intense radioactivity of the X-12’s power plant be kept from endangering the train crew, and passengers and bystanders on station platforms, too? Here was the stumbling block for would-be designers of A-locomotives, concluded one survey of atomic-power possibilities that was published by Princeton University in 1950. Its authors reported that stopping the deadly rays would take at least 100 tons of shielding, seemingly too

Inside the Hot Engine



much bulk to fit within the clearance limits of a locomotive.

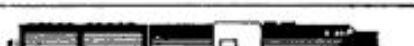
But the X-12’s designers have succeeded in shoehorning 200 tons of shielding, twice this amount, within the allowable limit of a locomotive’s breadth. To do it, they use such unconventional machinery as “dachshund” generators with rotors eight feet long, which can be squeezed into spaces only two feet wide and deliver the needed power.



Thus the reactor can nestle within a massive block of shielding four feet thick, measuring 10 by 15 by 15 feet over-all. It will consist of alternate layers of steel, to confine gamma rays; and of a neutron-stopping "hydrogenous material," which could be water, paraffin or plastic.

How can safeguards be provided against the new peril of radioactivity on the loose, in case of a wreck? First, the successive steel layers of the massive

shielding will keep a collision from spattering the wreckage with radioactive soup; even if some layers were ruptured, others would remain intact. Second, a crash would automatically shut down the reactor. Control rods are mounted at 60 degrees from the horizontal, and each mounting includes a shear pin, or weak link. An impact from any direction exceeding a force of 1/5 of a "G" will snap the shear pins, and momentum and grav-

TYPE OF LOCOMOTIVE	WEIGHT	LENGTH	DRIVING WHEELS	HORSEPOWER	FUEL CAPACITY
 STEAM (UNION PACIFIC'S "BIG BOY")	597 TONS	130 FEET	16	6,670	COAL: 28 TONS WATER: 25,000 GAL.
 ELECTRIC (VIRGINIAN'S MOTOR-GENERATOR TYPE)	500 TONS	150 FEET	32	6,800	—
 FOUR-UNIT DIESEL (GENERAL MOTORS' F-7)	486 TONS	201 FEET	32	6,000	FUEL OIL: 4,800 GAL.
 GAS TURBINE-ELECTRIC (UNION PACIFIC)	250 TONS	84 FEET	16	4,500	FUEL OIL: 7,000 GAL.
 ATOMIC (X-12)	360 TONS	160 FEET	24	7,200	URANYL SULFATE SOLUTION: 64 GAL. (CONTAINING APPROX. 20 LB. U 235)

ity will do the rest. From withdrawn position, the control rods will be driven or will fall back into the center of the reactor, stopping the chain reaction.

When the locomotive is running at full power, the nuclear reactor will develop heat at the rate of 30,000 kilowatts, and the soup temperature will be 455 degrees F. While this temperature rapidly vaporizes the boiler water in the tubes, the uranium-solution soup itself will not boil, because of the pressure of 650 pounds to the square inch under which it is confined in its vessel.

But provision must be made for another thing that happens to it, and a strange one.

Water Must Be Reconstituted

Under the intense radiation of the reactor, the water of the soup breaks down into hydrogen and oxygen gas—at a rapid enough rate for 10 percent of the 64 gallons of soup to be lost in only 13 minutes. To offset this and maintain the volume of soup intact, the hydrogen and oxygen gases are led to a novel auxiliary device called a recombination chamber. Here a chemical catalyst reunites them, to form water again, and the water is returned to the soup vessel.

In all, then, there are three separate water-circulating systems: for the reactor's soup; for the boiler water and the steam it makes, which is condensed and piped back to the boiler after driving the turbine; and for the cooling water of the steam turbine's condenser. Since each

is a closed system and returns the water to its original source, the water consumption of the X-12 is negligible.

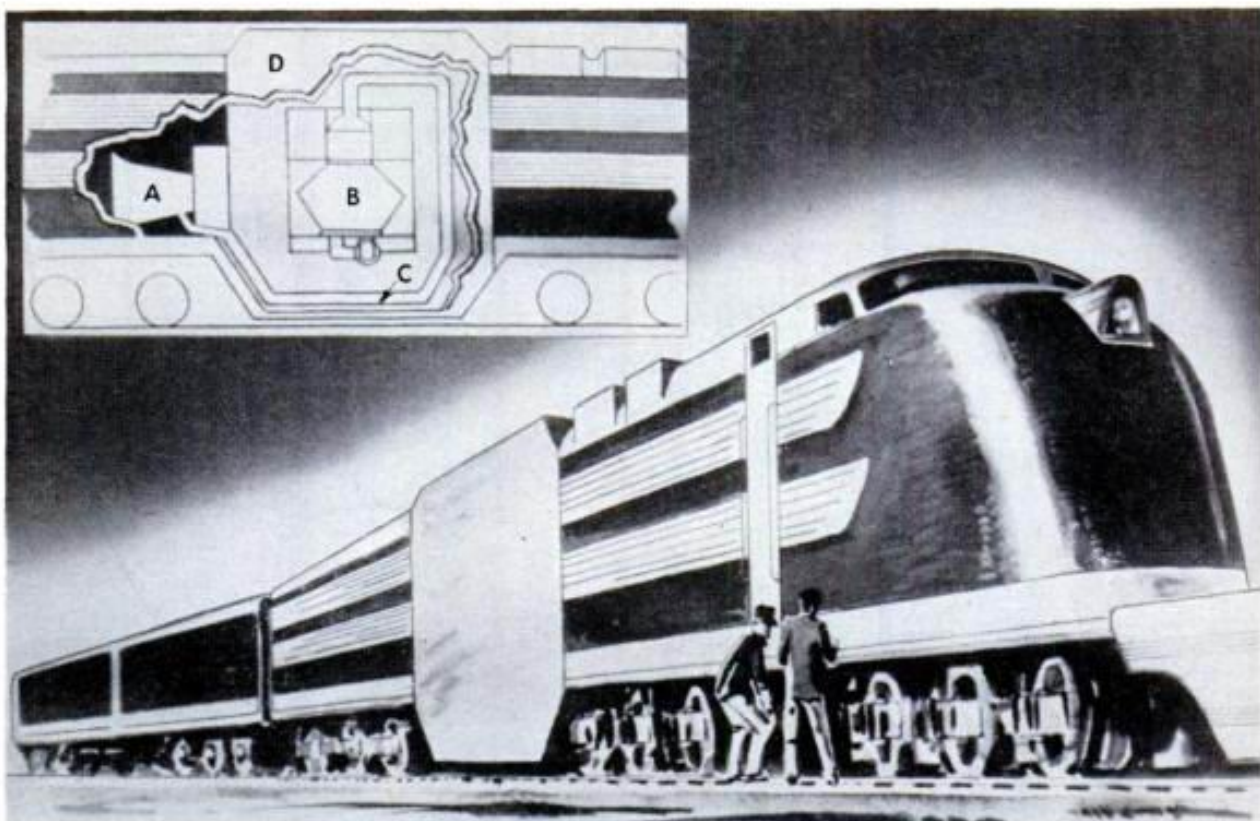
Refueling will be a major operation requiring two to three days, and to be performed only by atomic experts skilled in handling "hot" materials with remote-control implements. It must be done three to six times yearly. While only 10 percent of the uranium may have been consumed in the interval, enough atomic "ashes" or fission products will have accumulated to hinder the chain reaction. So the soup must be drained from the reactor, purified in a chemical plant and replaced, together with enough fresh fuel to make up the original amount. As the designers foresee, this will call for "elaborate and costly facilities." At first, A-locomotives could best be refueled at special "atomic-fueling stations" established and operated for the purpose by the AEC. Eventually, the railroads might undertake the job.

Maintenance Is "Designed Out"

Maintenance, too, will be an unprecedented problem. Inevitably some radioactivity will contaminate the steam turbine—and keeping a "hot" turbine in repair hardly seems an appealing task. But unlike a reciprocating diesel engine, a rotating turbine is a balanced machine and requires comparatively little maintenance.

As for a nuclear reactor, maintenance work must be "designed out" at the

[Continued on page 276]



Atomic Locomotive May Produce 7000 Horsepower

Atomic locomotives can be built, and if the cost of their uranium fuel is not too high they can compete successfully with diesel power. These are the conclusions of Dr. Lyle B. Borst, nuclear scientist of the University of Utah, who has been supervising a study of atomic power for locomotives, sponsored by five railroads and nine manufacturing corporations. According to Borst, the uranium fuel would produce heat, which would produce steam, which in turn would produce electricity to provide

the power. About a pound of uranium fuel would be added every few months. The locomotive would consist of two sections. The first would support a reactor only three feet long. The reactor would be housed in a steel block four feet thick and weighing 200 tons, which would protect the crew from radiation. The second section would carry huge radiators to get rid of the heat produced by the reactor. Borst estimates the locomotive would cost about \$1,200,000 and would produce 7000 horsepower.

American Sports Car Has European Origin

American sports-car enthusiasts can now buy a "domestic" sports car that is European in everything except name. The car

is the Arnolt-Bristol, being sold by the S. H. Arnolt Company of Warsaw, Ind. The Car Division of the Bristol Aeroplane Company

builds the car in England.

The body was designed by

the Italian, Bertone of

Turin. Weighing under

2000 pounds, the Arnolt-

Bristol has a 96-inch

wheelbase. Its engine de-

velops 130 horsepower.

The four-speed transmis-

sion has a free-wheeling

first gear for ease of en-

gagement. A one-shot lu-

brication system is built

into the chassis. By press-

ing a foot pedal, the driv-

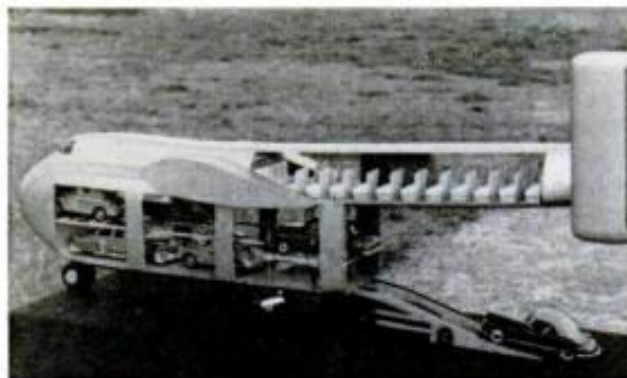
er gives the entire chassis

a grease job.





Three-Deck Aerial Auto Ferry Now Hops English Channel



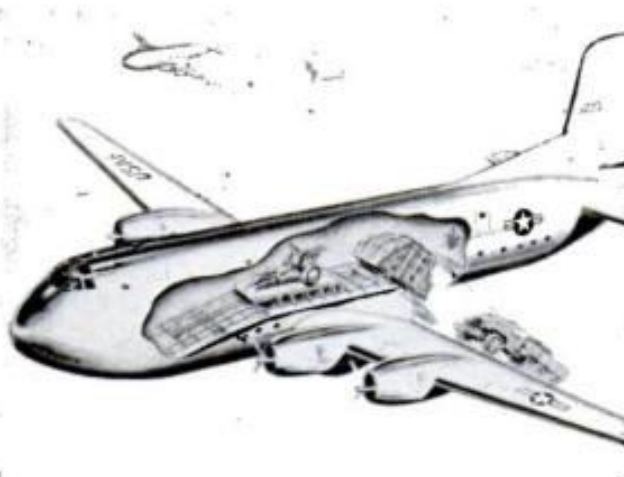
A LONDON passenger and his car are now only 85 minutes away from Paris. A 42-ton, four-engine Blackburn Beverley freighter of the Silver City Airways regularly ferries 42 passengers and six automobiles across the English Channel at more than 175 miles an hour.

The cars are loaded onto a double cargo deck through the rear of the plane's fuselage (see model at left). An electric elevator lifts three of the cars to the upper deck.



Fast Copter Carries Jeeps

THE Marines' new helicopter can stow three Jeeps in its fat fuselage. Two engines, encased in teardrop compartments, give the Sikorsky XHR2S a speed of 150 miles an hour—fast for a whirlybird. Retractable landing gear lends the big aircraft a streamlined look in flight. It can carry 26 men, fully combat-equipped.



Plane Drops Big Stuff Pronto

PARACHUTE delivery of a field piece, several hundred rounds of ammo and a truck takes no time at all with a new system installed in an Air Force Douglas C-124 cargo plane. Each unit is lashed to a pallet, on tracks and hooked to a chain drive. At the touch of a switch, 40,000 pounds of cargo can be dumped in a few seconds.

1945  1955

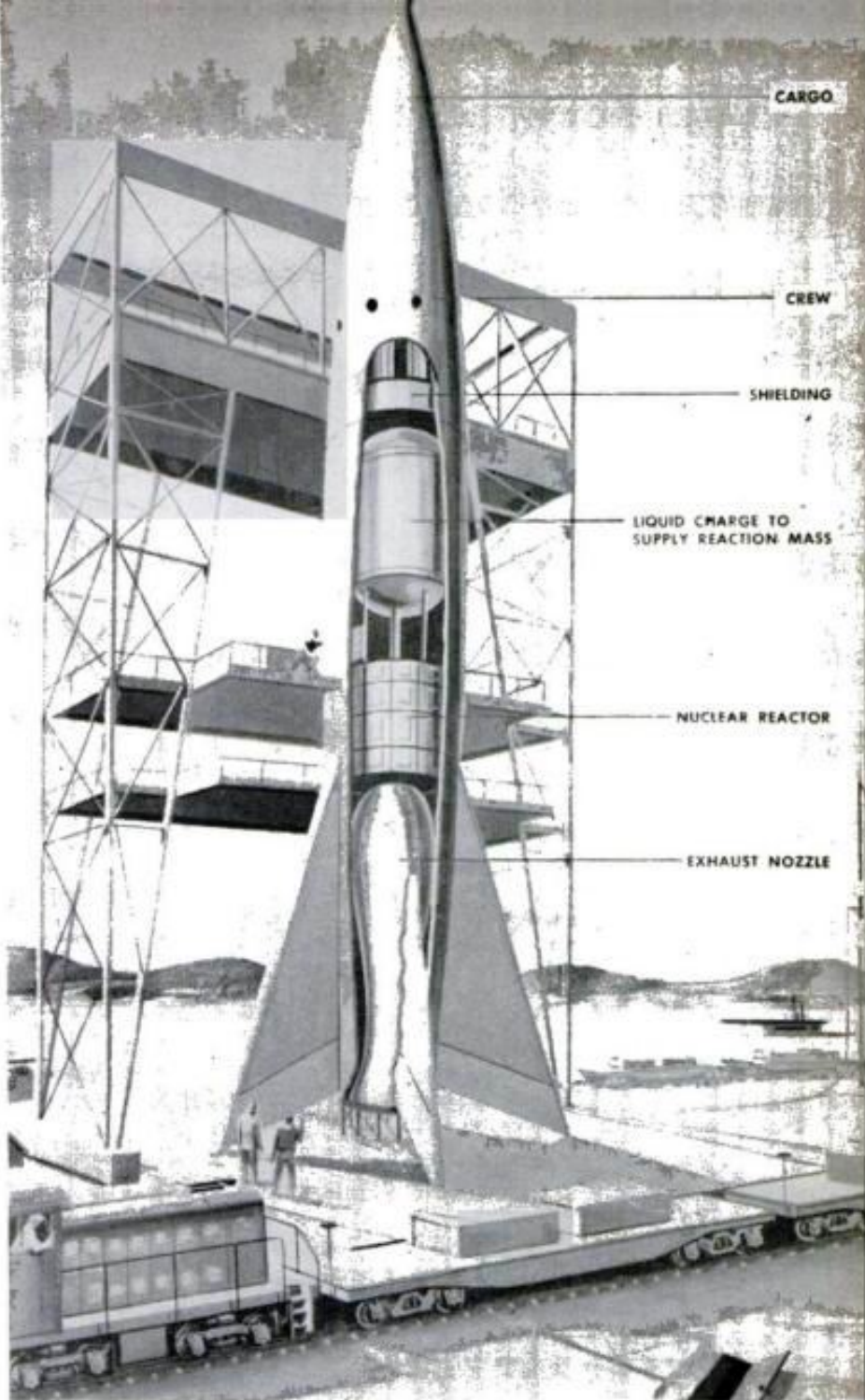
TOMORROW:

Atomic Travel

LOOKING ahead, experts foresee that we'll travel in ships like the ones pictured on this page.

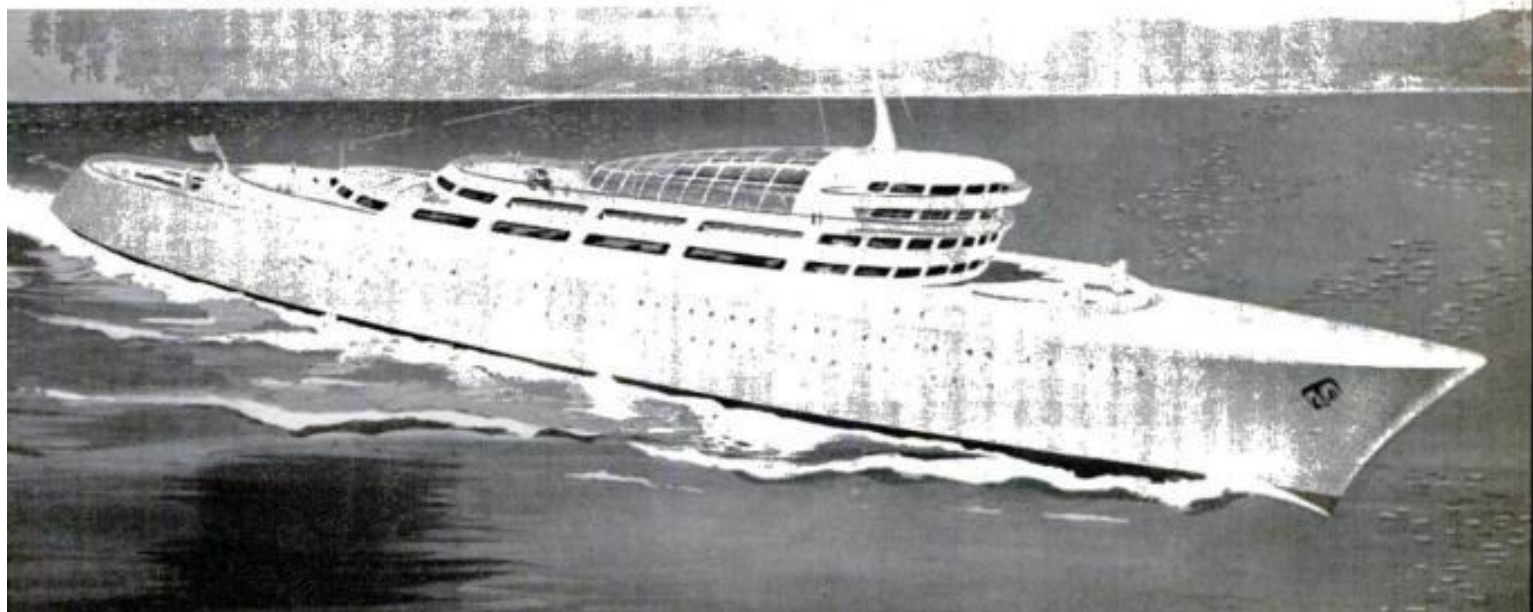
Atomic ocean liners may be near. Since last October, the Bethlehem Steel Company's shipbuilding division has been perfecting plans for the 500-passenger, 600-foot vessel illustrated below. It would have long range without refueling, and dispensing with fuel-oil tanks would make more room for cargo.

An atomic spaceship, General Electric engineers say, awaits more novel and distant developments: a reactor yielding electricity directly, and an engine shooting a jet of electrified particles rearward for propulsion. Laboratory experiments suggest that both may be possible.

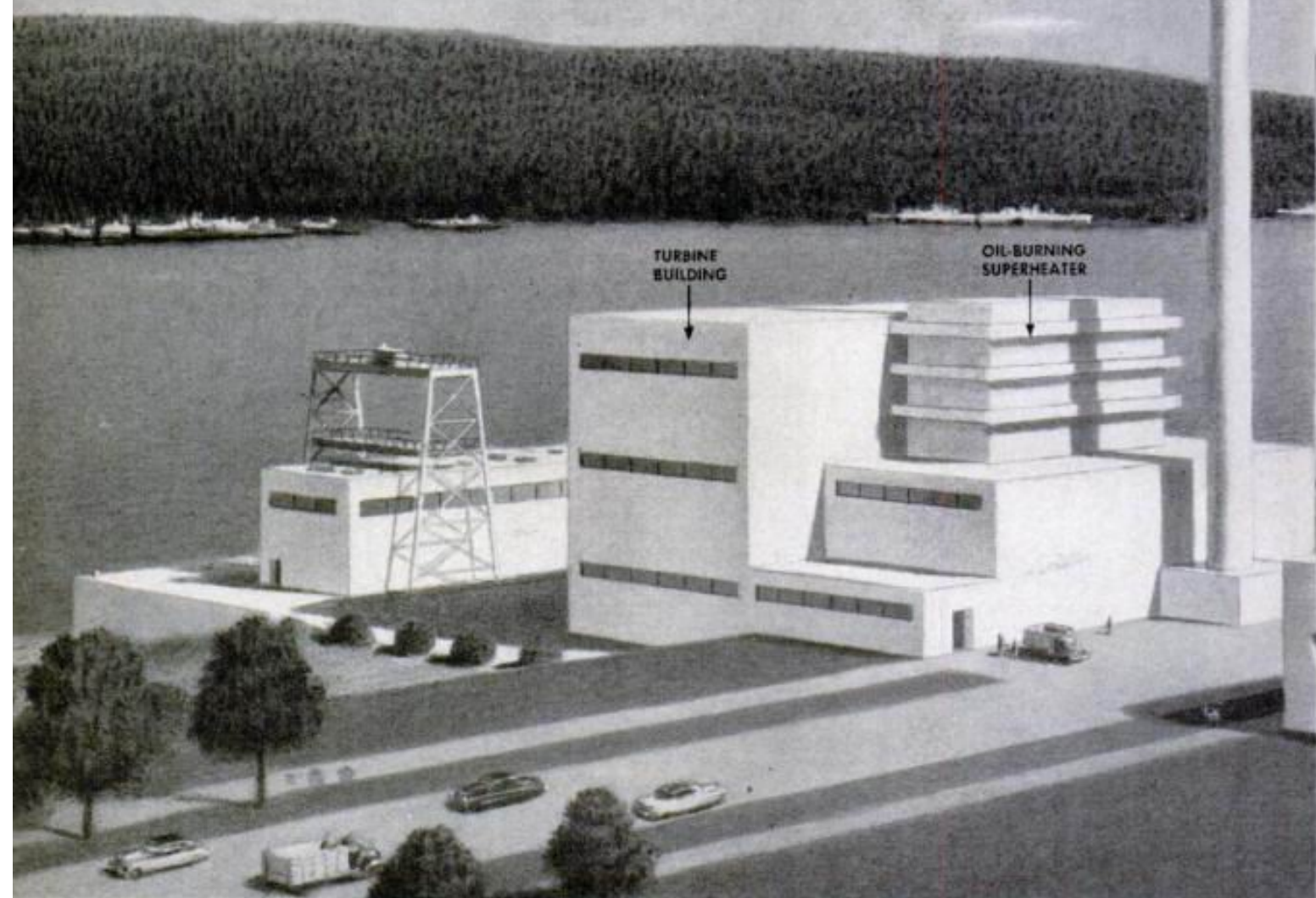


Atomic spaceship, still far in future, may look like this.

Atomic liner may come soon. Stackless reactor makes steam to drive turbines and screws.



Atomic Power Plant



By Martin Mann

NEW YORK CITY'S electric company is planning a new power plant. What's unusual is that this one will run on exploding atoms. By the end of 1959, Times Square may sparkle with atomic electricity.

From any angle Consolidated Edison's venture will be a remarkable breed of generating station.

It will be the biggest of the five U.S. atomic electric plants now proposed, with a capacity of 250,000 kilowatts. That's enough for half a million homes, and a comfortable addition to Con Ed's present capacity (from nine stations) of 3,500,000 kilowatts.

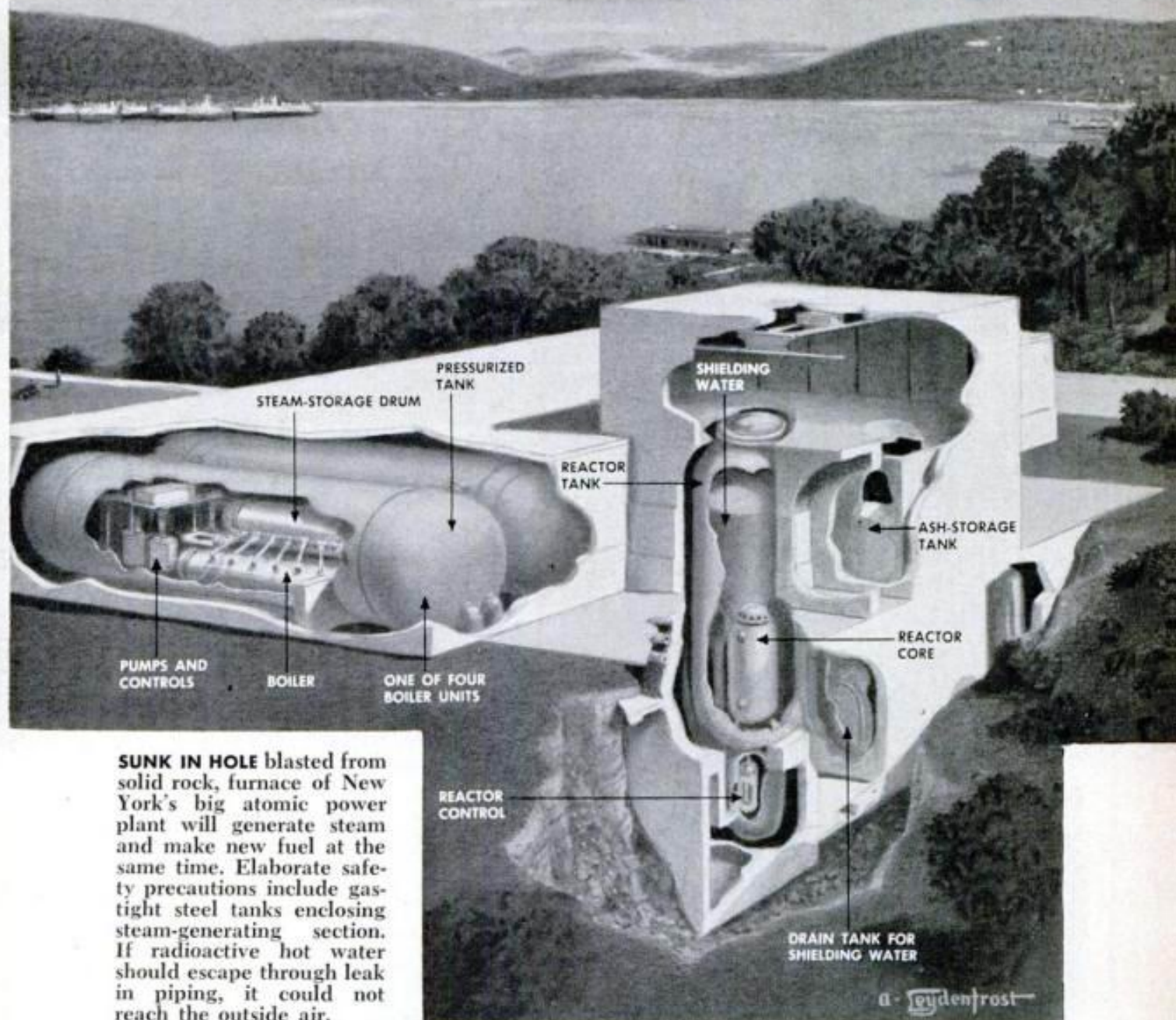
The atomic furnace will manufacture part of its own fuel by converting an element called thorium into uranium. Some of this newly made uranium will be consumed to produce power. But the plant will also use ordinary fuel oil in a standard furnace that will make the atomic steam hotter for greater efficiency.

Unlike most atomic furnaces, which are located in remote areas such as Arco, Idaho, and Oak Ridge, Tenn., this one will be 24 miles up the Hudson River from the nation's biggest city, on an old picnic ground between Peekskill and Buchanan, N. Y. There are 45,000 people living within five miles, although only 16 families live as close as half a mile.

Con Ed never forgets that its business

to Serve New York

The country's biggest, it will burn a combination of uranium, thorium—and ordinary fuel oil—to make 250,000 kilowatts, enough for half a million homes.



SUNK IN HOLE blasted from solid rock, furnace of New York's big atomic power plant will generate steam and make new fuel at the same time. Elaborate safety precautions include gas-tight steel tanks enclosing steam-generating section. If radioactive hot water should escape through leak in piping, it could not reach the outside air.

is power, not research, and it set out to get a plant that would make electricity practically, safely and cheaply.

"We were pleasantly surprised," remarks the company's bespectacled, professorial engineering v-p, Jim Fairman, "to learn that it wouldn't be as costly as we had feared. The plant will run around

\$230 a kilowatt. That compares favorably with the \$200 a kilowatt we would have to spend for a new conventional plant. Operating costs should be less than at some of our older stations."

Old reliable PWR. The atomic furnace Con Ed chose is a "pressurized water reactor," as tried and tested a



SPACE-STATION SERVICEMAN for moon-bound ships floats free of gravity. To get about, he squirts gas jet. Spacesuit has oxygen supply and radio, with direction-finder loop.

Rocket Experts Show How We Can Live on the Moon

SPACE adventurers can reach the airless moon, survive its rigors and set up permanent colonies there. So predicts Ralph A. Smith, English rocket expert and artist, whose drawings on this and the next two pages show how they'll do it. The views are from a series of 45 in a new pictorial book, *The Exploration of the Moon*, published in this country by Harper & Brothers, New York. Its accom-

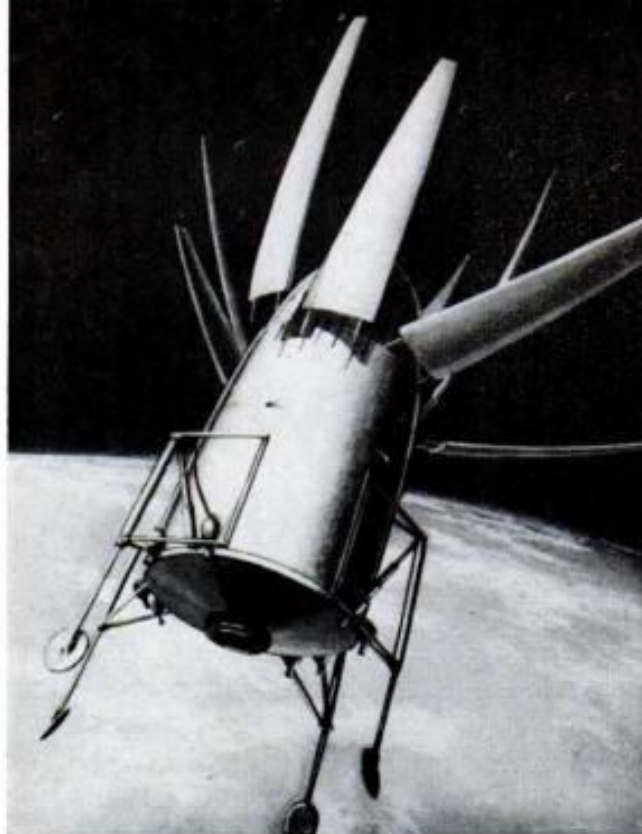
panying text is contributed by Arthur C. Clarke, noted British writer on interplanetary flight.

Pioneer settlers on the moon face a forbidding world. Water to drink and, at first, even oxygen to breathe must come by spacelift. But future lunar colonies with atomic power and air-purifying plants may make such early hardships a memory, the artist and writer think.

TWO-STAGE ROCKETS like this one would set up and tend refueling station a few hundred miles

above earth. Lower stage, fuel spent, drops off (right); manned upper stage climbs on.





EARTH-TO-MOON ROCKET, having dropped two of three stages, shucks streamlining with small explosive charges. It will never re-enter air, but shuttle between moon and space station.

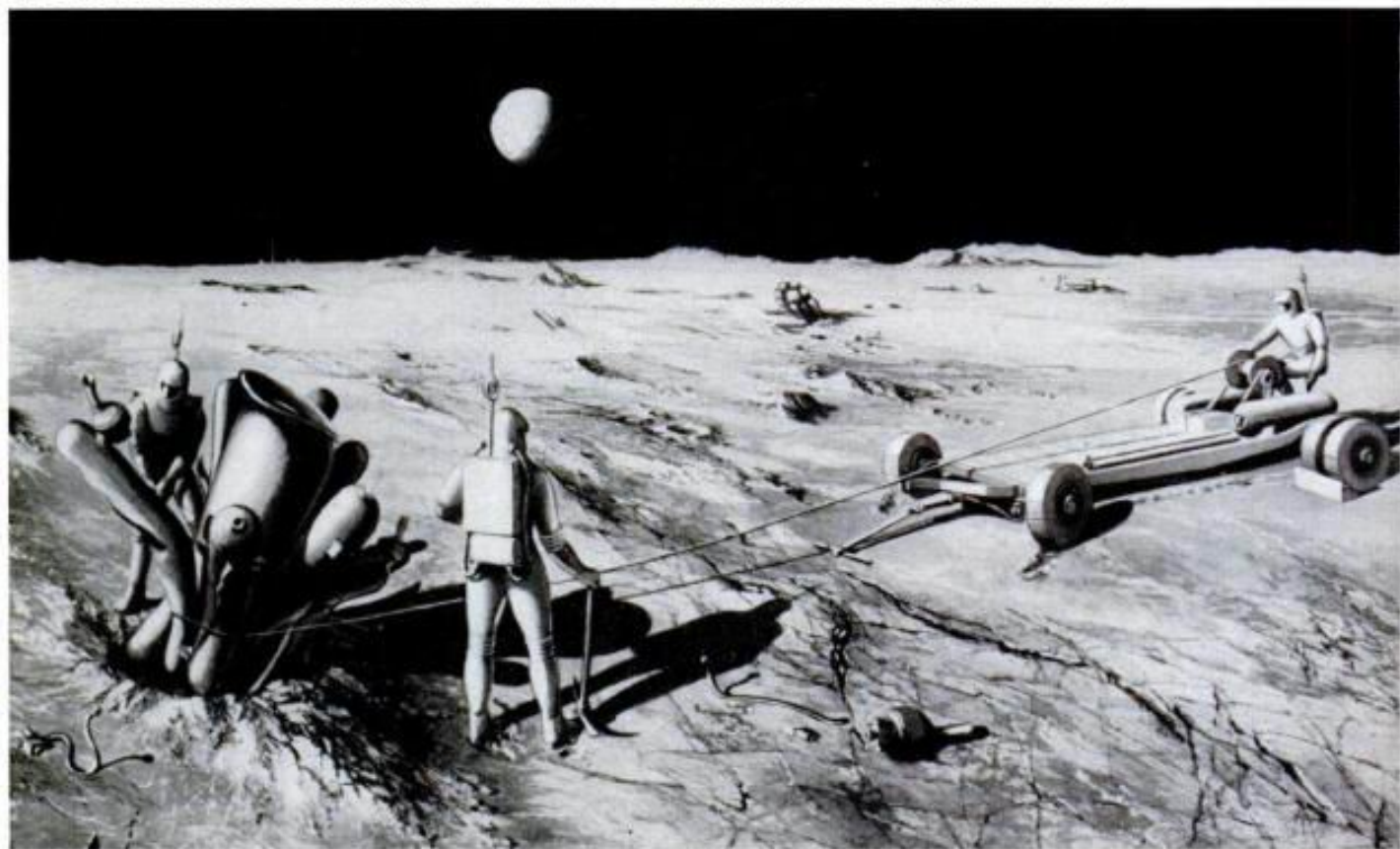


LANDING ON MOON climaxes last leg of journey, after refueling stop at space station. Ship's crew uses rockets to brake descent and to correct tilt. Flexible landing gear takes impact.

First a landing on the moon, then pioneer

SUPPLIES DROP TO EXPLORERS, who require constant spacelift of food, water and oxygen. By radio control, piloted spaceships guide fleets of robot cargo rockets to dropping area. Battered

but intact bundles surround a robot, left, that has made rough landing. Tractor retrieving supplies is powered by turbine using rocket fuel. Earth hangs in the sky above scene.





MOON EXPLORERS pitch camp. Inflated plastic spheres with airlocks serve as living quarters. Heap of rock dust covers one, at left, for protection against extremes of heat and cold.

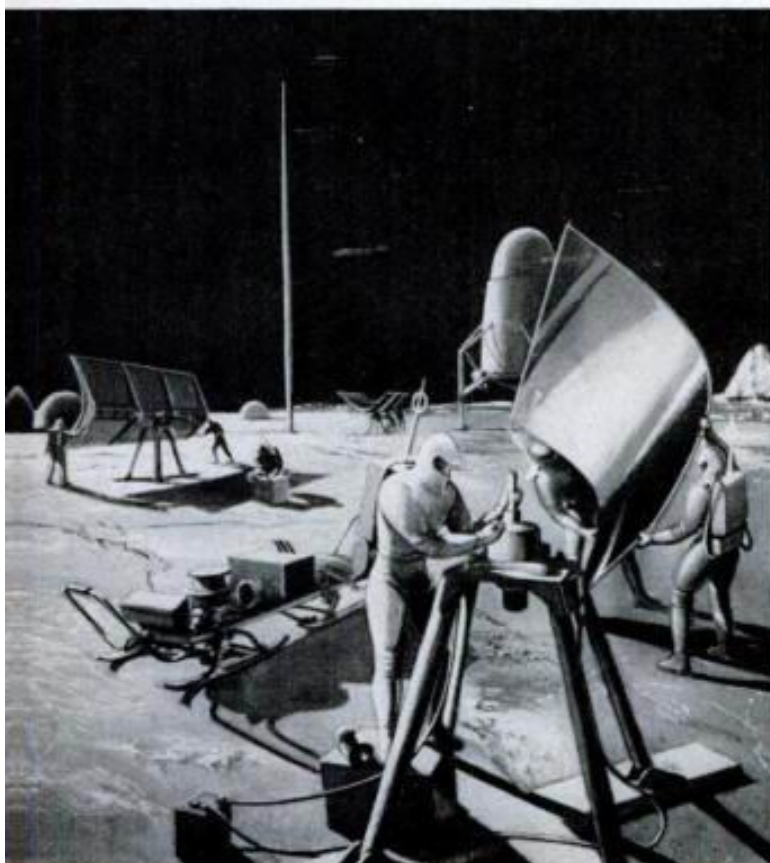


HOME ON THE MOON: inside a plastic sphere. Scientist at microscope is studying mineral specimens. Behind him, radioman talks with distant earth. Cylinder on ceiling holds oxygen.

bases—and perhaps, some day, lunar cities?

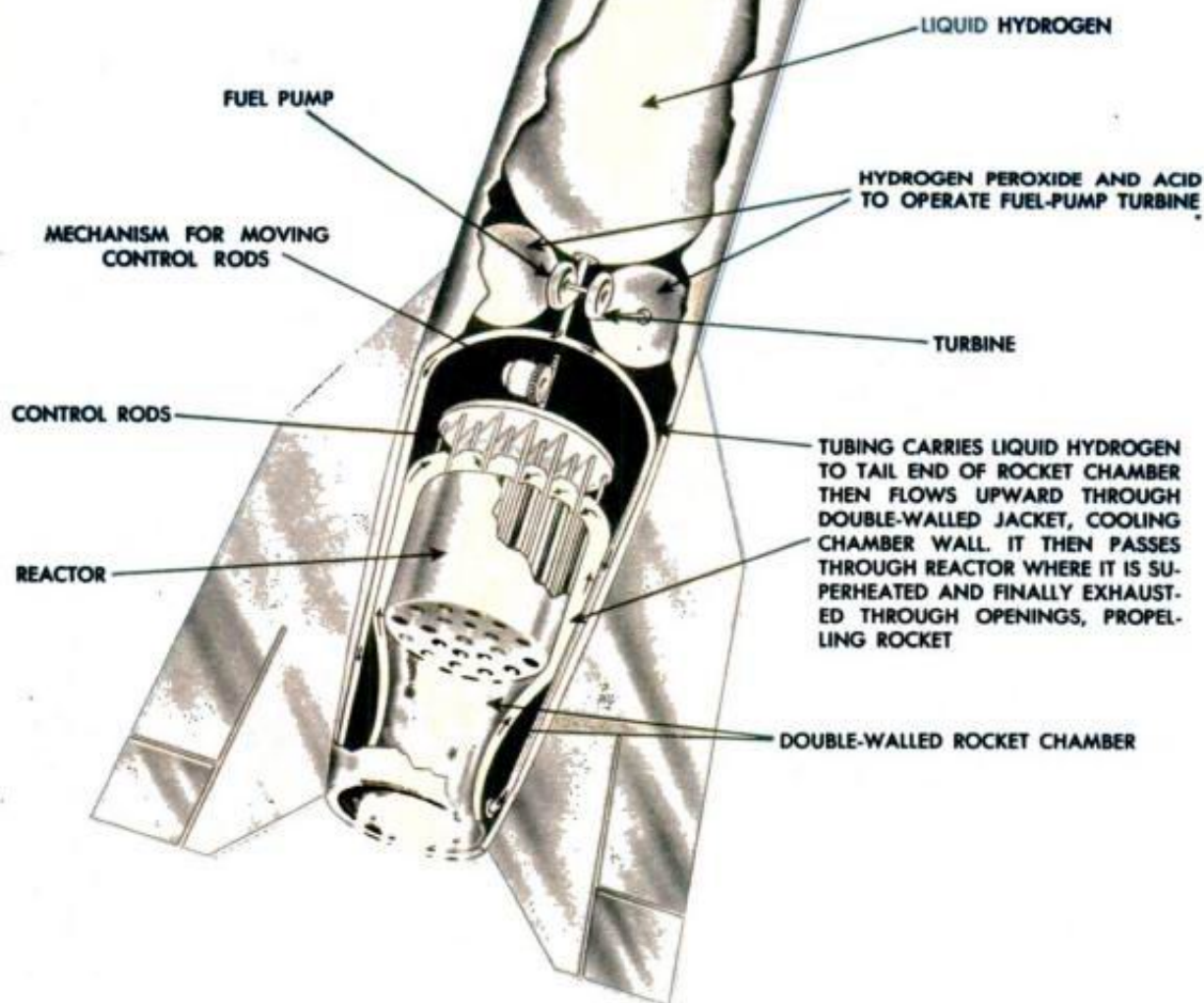
PIONEER SETTLERS' EQUIPMENT includes solar-powered generators; radio mast, an inflated rubber tube; and sledge, easy to haul, since things weigh only one-sixth as much as on earth.

ROCK DOMES enclose spacious, atomic-powered lunar city of more distant future. Algae farms in tubes renew air, augment food supply. Overhead railway links moon colonies. END



ATOM POWER

Goes



into GEAR

By
Richard F. Dempewolf

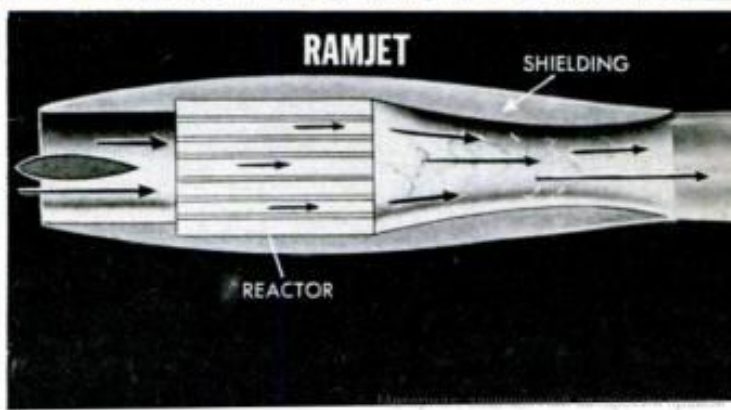
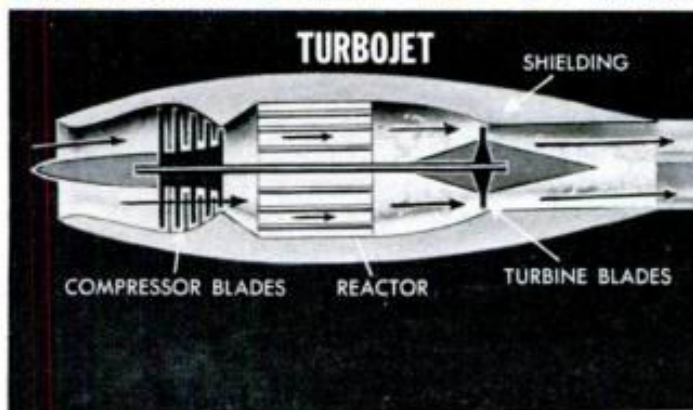
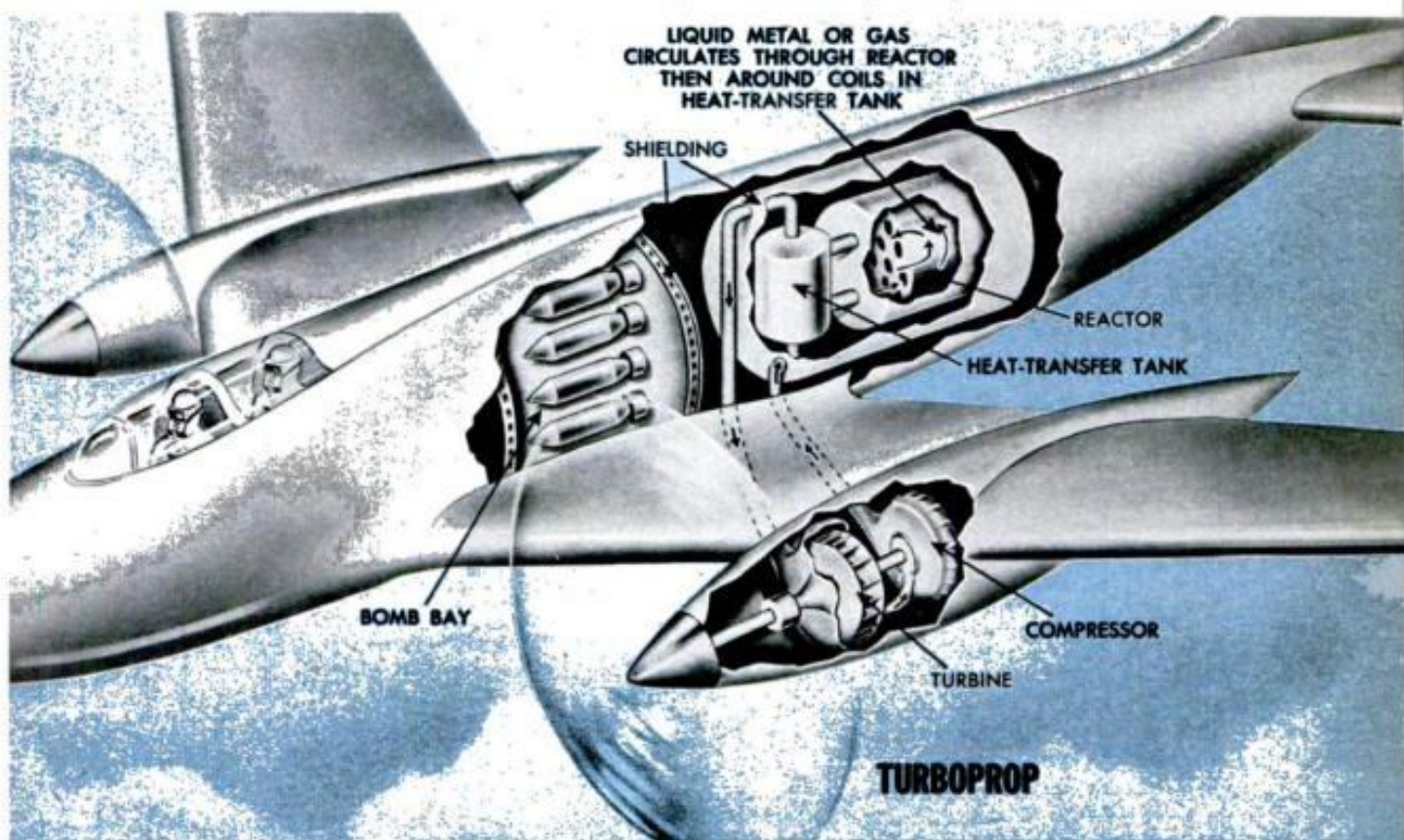
WE'LL NEVER SEE uranium pills to run cars or home heaters. Neither will we see those atom furnaces that would melt the Greenland icecap and make a tropical garden of Alaska. Such nonsense was forecast by post-Hiroshima enthusiasts whom Dr. Lawrence Hafstad, the Atomic Energy Commission's boss of atomic piles, calls "subsophomore slapstick artists." But atomic power today is far from the hopeless will-o'-the-wisp that some pessimists would have us believe.

Here and abroad, vast new reactor programs are in high gear. An atom-powered ship that can cruise for months without refueling is no longer pure "pie in the sky." At Britain's huge Harwell atomic station, experimental work on a submarine pow-

ered by uranium fuel has reached a stage where experts are now working out figures and designs for the prototype. Our own plans for a high-speed atom-powered submarine with vastly increased range are complete. One Navy land-based prototype of the reactor that may power the ship is already being constructed under the supervision of Westinghouse at AEC's reactor-testing station in Arco, Idaho. Another is being designed at the Knolls Atomic Power Laboratory operated by General Electric for the AEC at Schenectady, N. Y. It's all part of a whopping \$90,000,000 AEC atomic-power program.

More money and fresh brains have been thrown into the top-secret U. S. project for harnessing atomic power for aircraft and

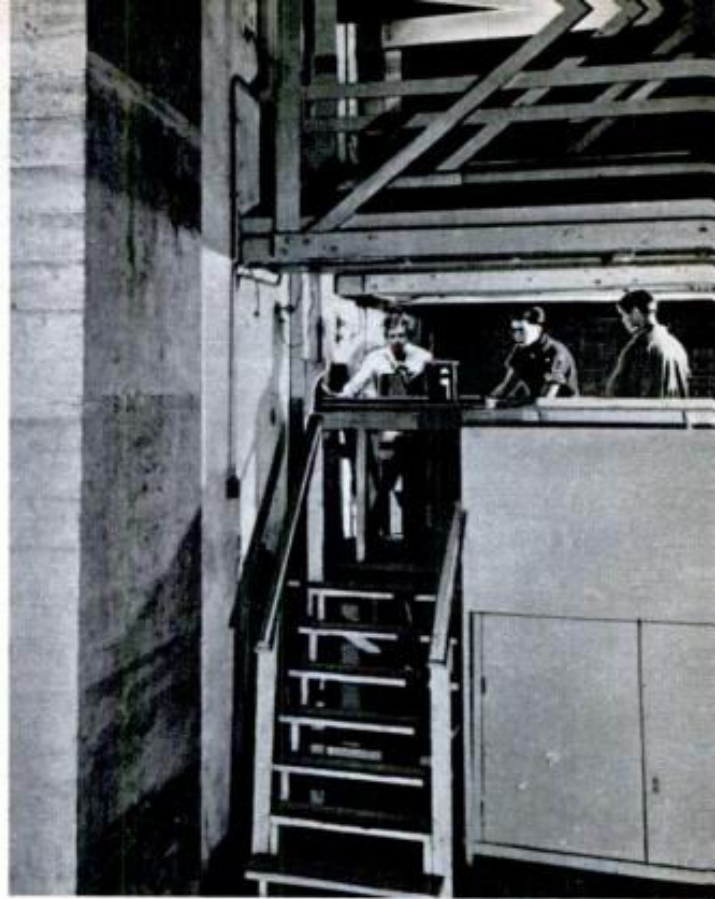
On opposite page is an artist's conception of the atomic-powered rocket. Liquid-hydrogen fuel would permit flights above earth's atmosphere. Below, three types of nuclear-power plants for tomorrow's aircraft



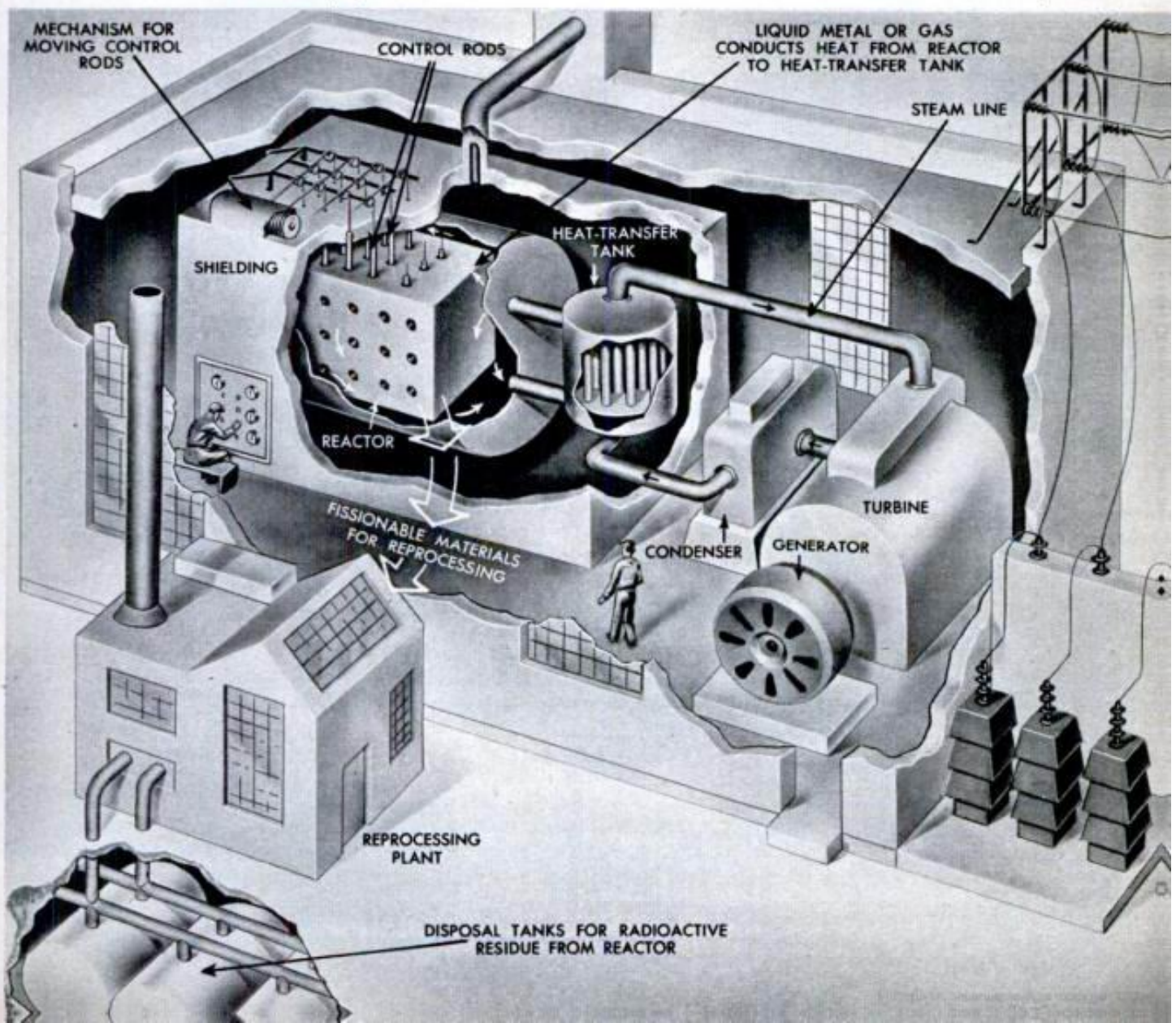
or surface craft in the world. She'll have four times the horsepower of her most powerful diesel sisters. Her atomic furnace will contain plutonium—a man-contrived atomic fuel made by bombarding U-238 with fissionable uranium. Her range will be globe-girdling, since one dose of fuel will last a long, long time. Her super-streamlined hull, designed primarily for underwater cruising, will make her faster when submerged than when operating on the surface—an unheard of thing in modern subs. She is expected to cruise down there at 25 to 30 knots, and will be able to stay down for interminable periods.

No air, of course, is needed to make her atomic furnace burn. Hence, no bulky snorkel will poke above the surface to cut a wake and give her away. Air for the crew can be banked at three to four-day intervals and a small, inconspicuous, retractable snorkel will do the job without any need to surface. The size of the atomic engine is small enough so that much of the space previously taken by some 700 tons of diesel oil and storage batteries will actually be saved for more torpedo storage.

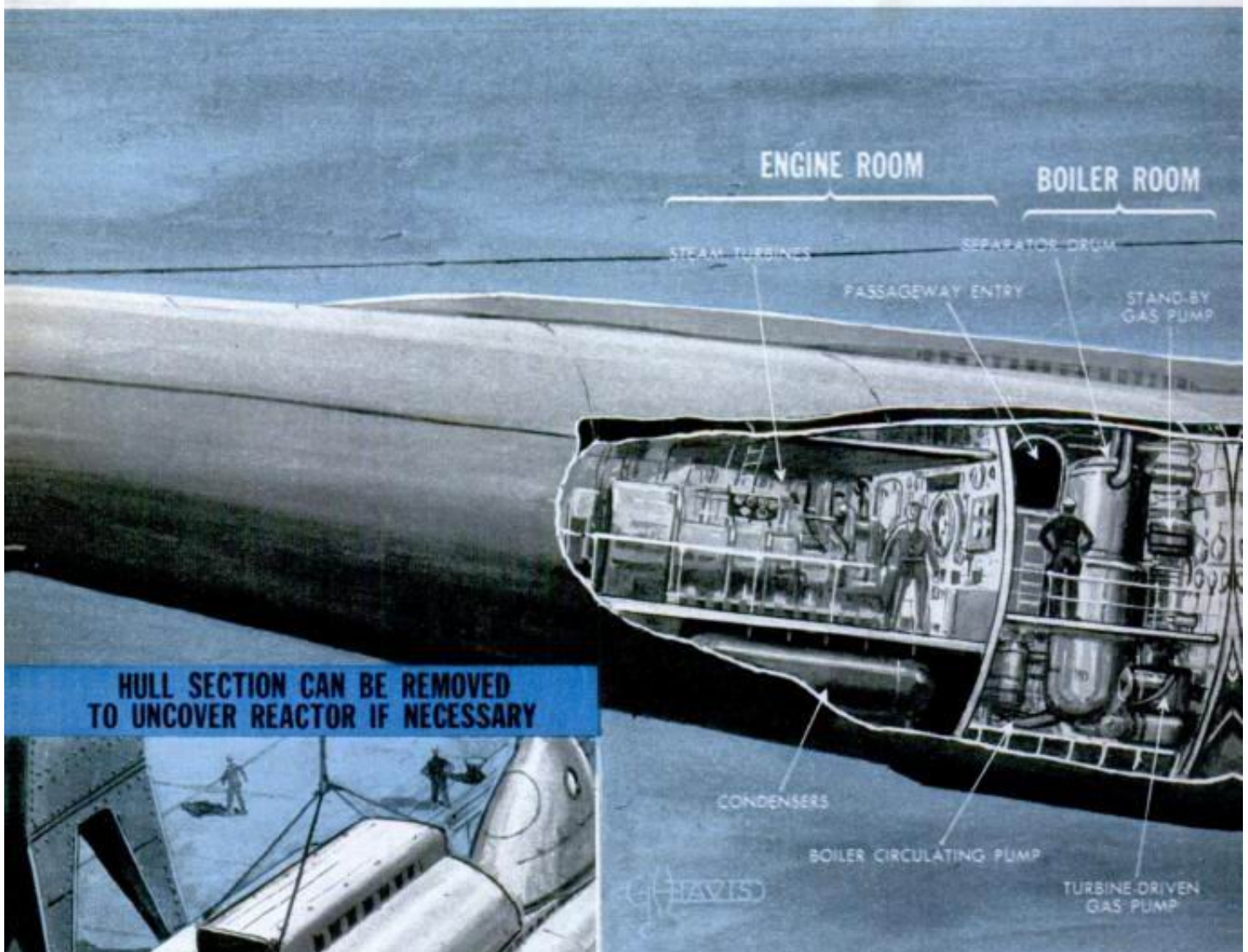
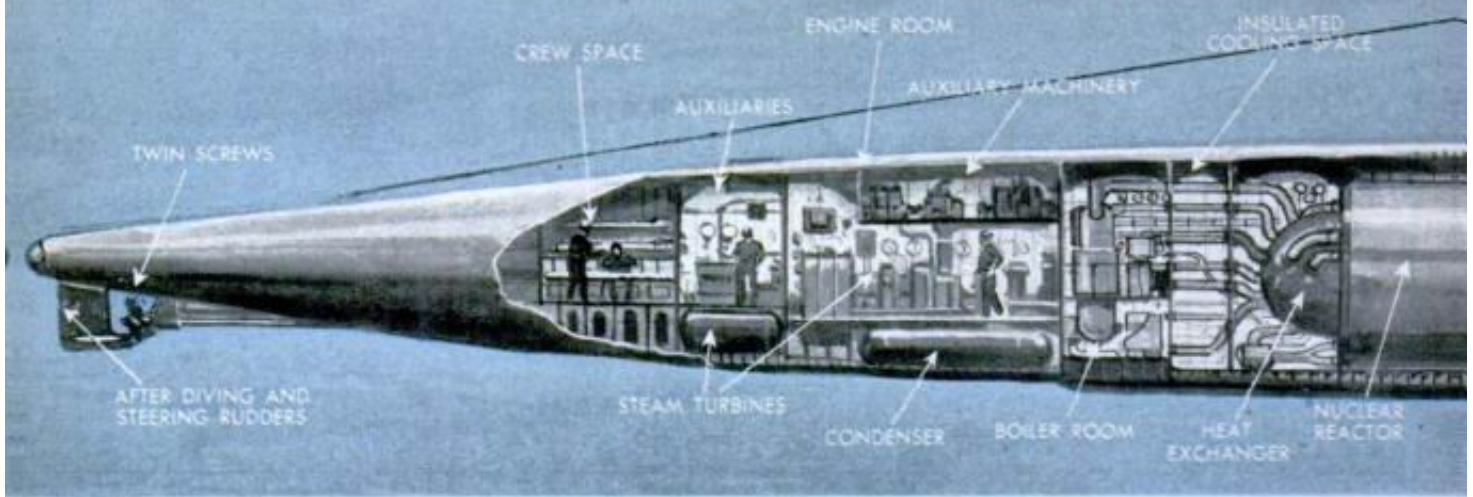
(Additional drawings on next two pages—story continued to page 234)



Above, the operating end of the pile at the Argonne National Laboratory. Below, an atomic-power plant



SECTIONAL VIEW OF NUCLEAR-POWERED SUBMARINE

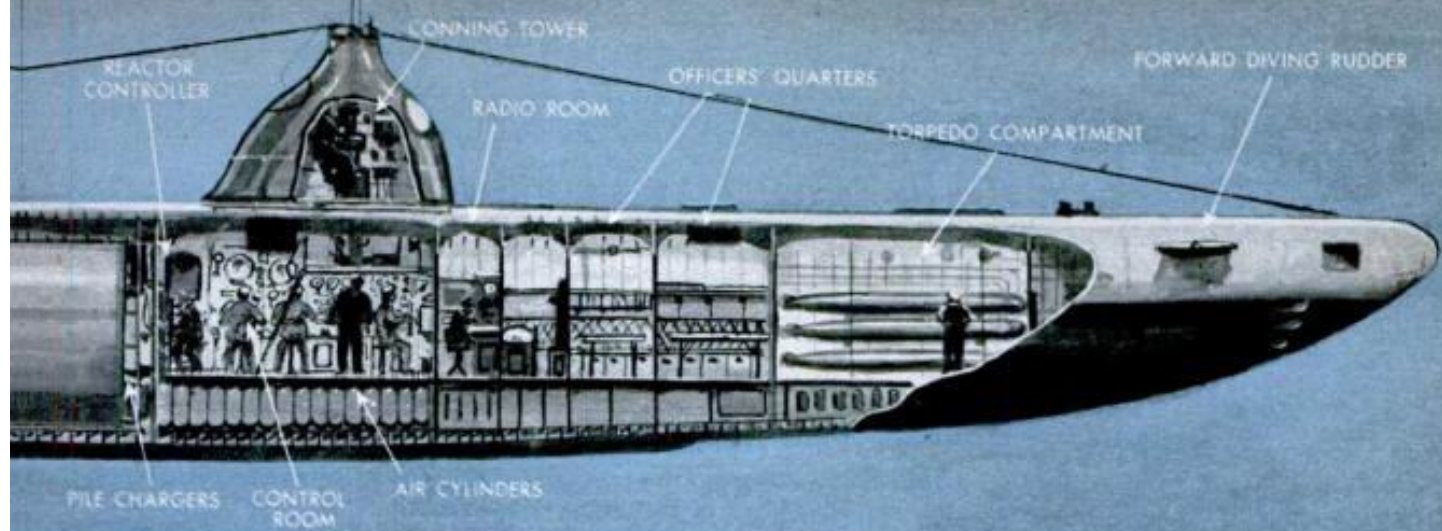


HULL SECTION CAN BE REMOVED TO UNCOVER REACTOR IF NECESSARY

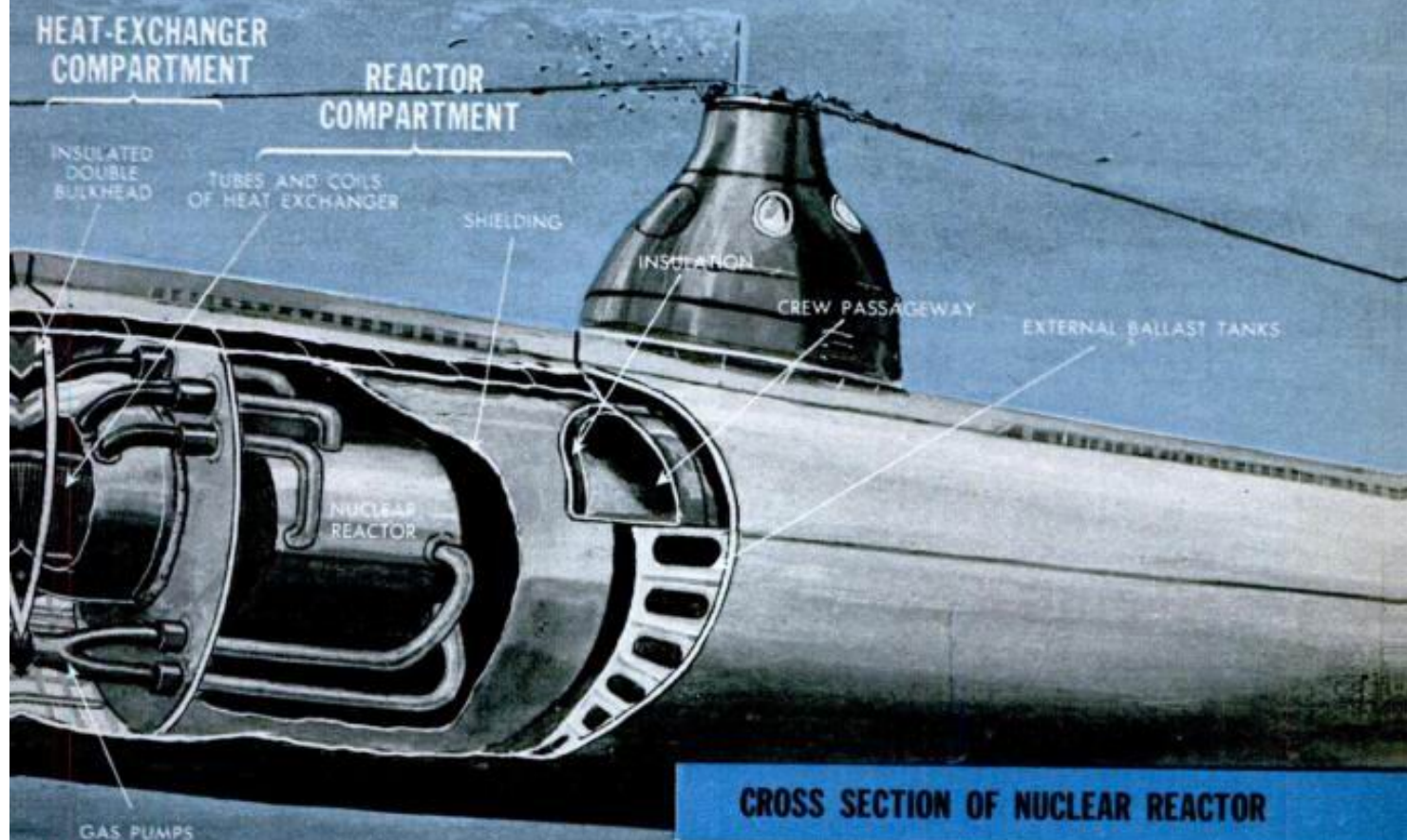


ATOMIC-POWERED SUBMARINE CHASER

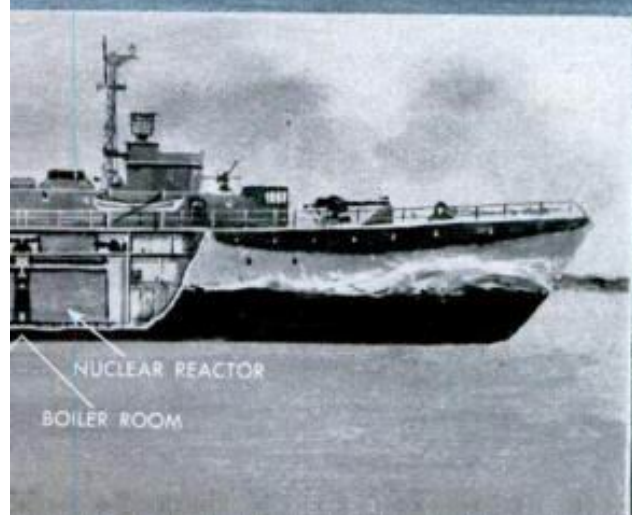




ATOMIC-POWERED SUBMARINE



CROSS SECTION OF NUCLEAR REACTOR



Atomic Engines to Power Rockets and

Nevada tests will soon try out newly revealed U. S. plans for sensational flying reactors

By Alden P. Armagnac

ON MESA-RIMMED Jackass Flats in Nevada, right next to our A-bomb testing site, trials of an extraordinary atomic reactor are about to begin. Riding a railway car that serves as a test stand, and towed by a remote-controlled locomotive, it's the prototype of an engine for a nuclear-powered rocket.

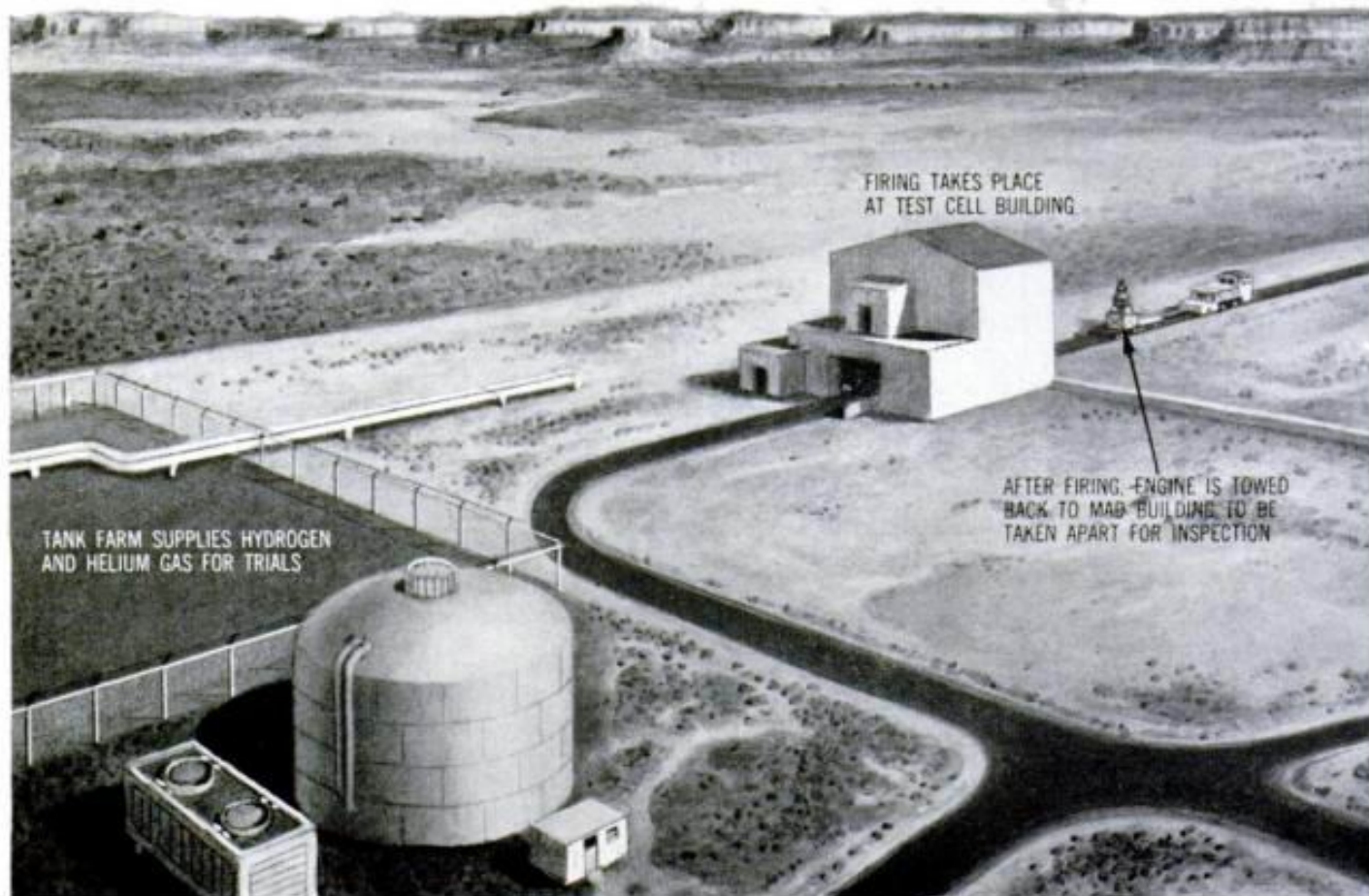
Cylindrical in shape, taller than a man, and weighing perhaps five or six tons, it will impart its fierce heat to a stream of hydrogen gas, which rushes through it and issues from a flaring rocket-style nozzle. Mounted upside-down for trial, the

uranium-fueled engine will direct its fiery blast toward the sky. Watching the fireworks, at safe distance from the unshielded reactor's intense radioactivity, will be the observers of Project Rover—our secrecy-shrouded atomic-rocket program.

Named Kiwi A for a flightless bird, the pioneering engine will serve for "static" or captive firing tests, due to start this month or next. Its purpose is to prove the early feasibility of building an A-engine that will actually propel a rocket.

Soon to become Project Rover's neighbors on Jackass Flats are two equally hush-hush programs, disclosed even more recently: Project Pluto, aiming at an A-powered ramjet missile; and Project Snap, auxiliary A-power for satellites.

Atomic Energy Commission scientists, it's revealed, have upset popular belief that such formidably difficult develop-



Missiles

ments as A-powered rockets, missiles and satellites would have to await the distant future. Quietly they've been making such phenomenal progress that actual hardware for all these vehicles is currently being groomed for trial.

Developing the atomic engines is the AEC's part of the task. Meanwhile the Air Force is designing the spacecraft and missiles to put them in. Spectacular possibilities spur the projects.

An A-rocket can be a super-ICBM. . . a giant-satellite launcher. . . an ideal vehicle to explore the solar system. Its incomparable advantage: in payload. Example: It can put a 50-ton moon into orbit to watch the world, take pictures, transmit intelligence—making Russia's 1½-ton Sputnik III look like a toy.

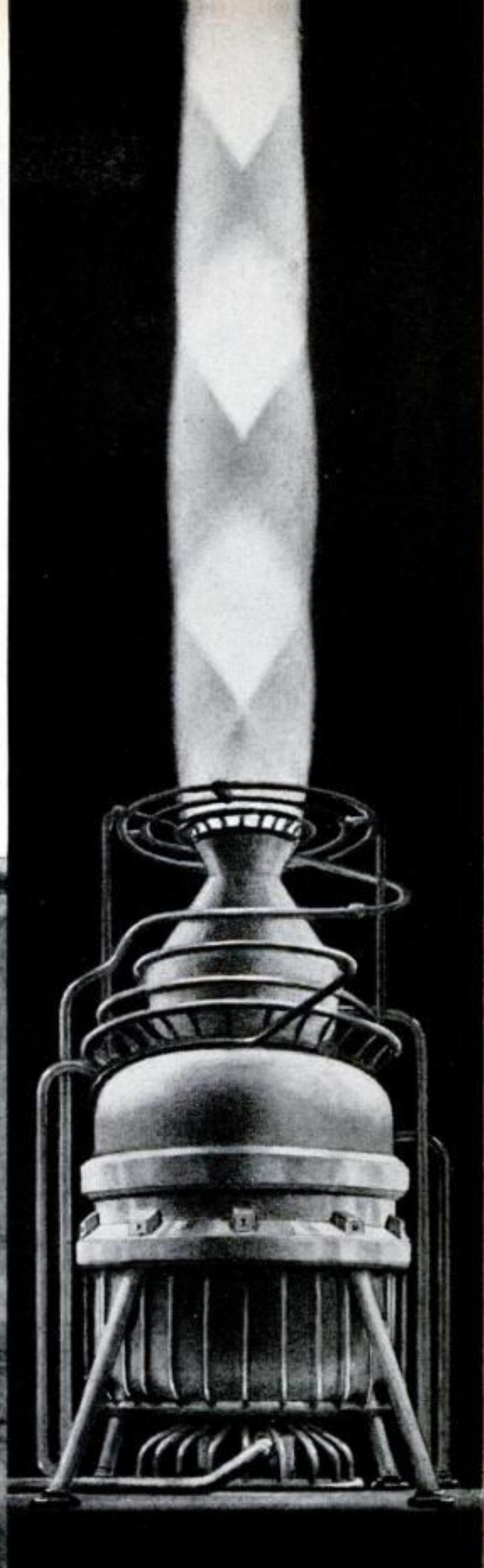
How will a rocket's A-engine work? In a chemical rocket, burning fuel yields

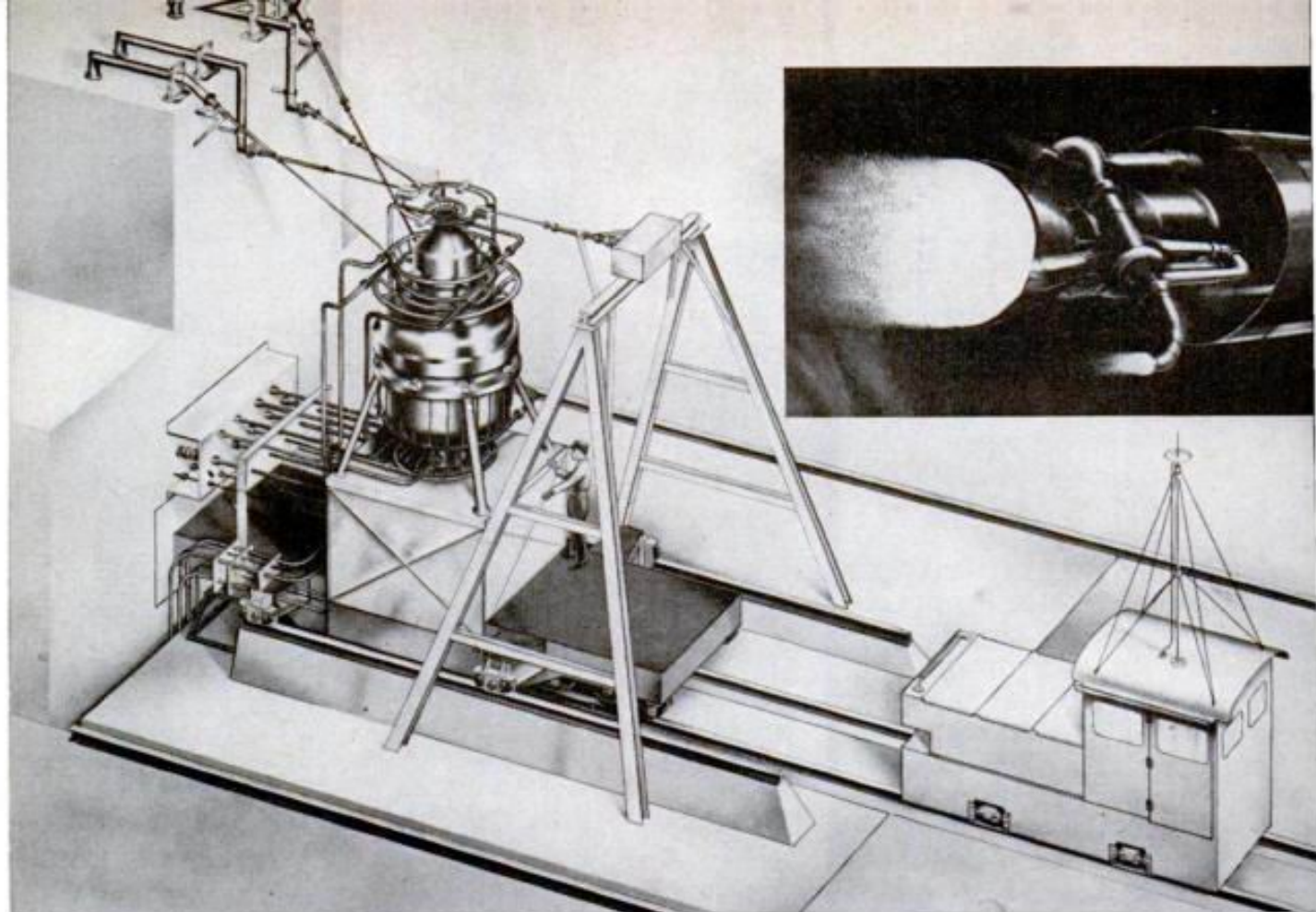
ROCKET A-ENGINE IS ASSEMBLED
AT MAD BUILDING FOR TRIAL

OBSERVERS RUN TRIAL
FROM BLOCKHOUSE-LIKE
CONTROL BUILDING

SPECTACULAR TEST of first rocket A-engine (right) and scene of its coming trials, at newly built Nevada site adjoining A-bomb proving grounds, are previewed by PS artist. Picture of site, intended as schematic view rather than exact map, is based on AEC description.

by Seymour Chwast





heat—and gaseous combustion products, which the heat energy expels from the nozzle to drive the rocket. In an A-powered rocket, the reactor just provides heat, which must be applied to something to make the rocket go. So an A-rocket will also carry a tankful of a “working fluid” or propellant—which is pumped to the reactor, heated by passing through it, and so expelled from the nozzle for propulsive force. For the propellant, most experts favor hydrogen, carried in liquefied form. (Other possibilities: ammonia, methane, even steam.)

First known attempt to put this principle into practice is Kiwi A, the product of the Project Rover team under Dr. Raemer Schreiber at the AEC's Los Alamos Scientific Laboratory. They call their engine weighty and bulky (“We haven't tried to shrink it down”) and its thrust “modest,” but it's quite a machine.

If it attains just a quarter of an Atlas missile's 360,000-pound thrust, its undisclosed power may exceed that of Shippingport's great atomic generating station. It's a high-power reactor, no *if* about that. And they'll run it at “up to a white-hot heat”—hotter by far than any reactor has been designed to run before.

The hotter the reactor, the better an A-rocket's performance.

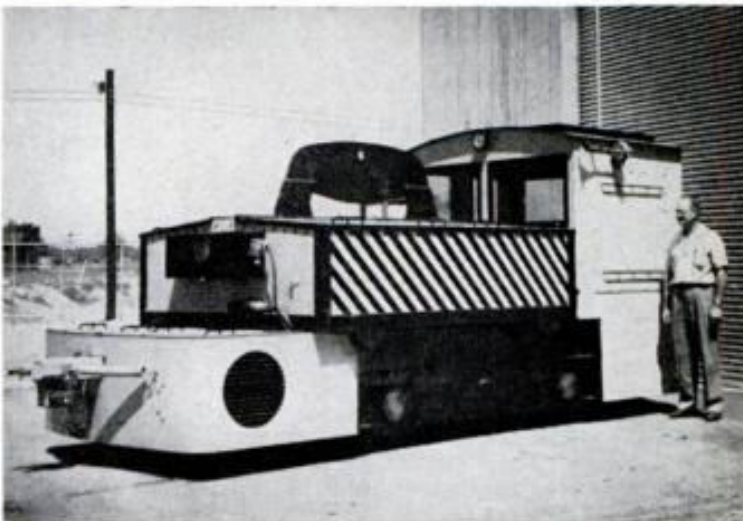
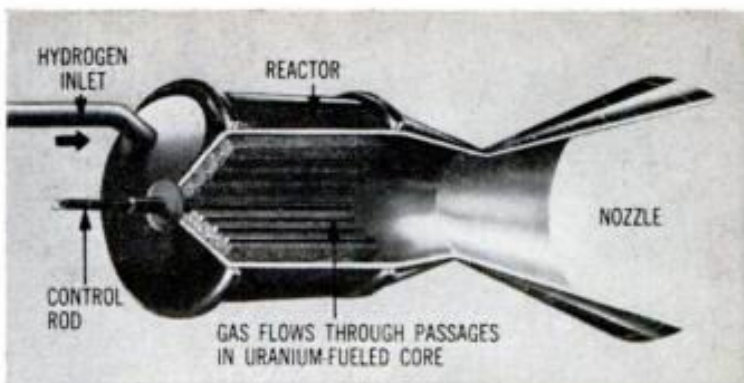
They'll assemble Kiwi A for trial at its Nevada site's MAD Building—a nickname that's short for “mechanical assembly-disassembly.” Trundled on its car to a Test Cell Building for firing, it will be connected to performance-recording instruments, and to a supply of gas from a “tank farm.” During the firing, the unoccupied test cell's instruments will transmit their readings to observers in a blockhouse-like Control Building. At trial's end, Kiwi A will be remotely disengaged from its connections—and the radio-controlled locomotive will tow it back to the MAD Building, to be taken apart to see what happened to it.

Initial trials at low power and heat, with helium gas as a stand-in, may take several months. Then Kiwi A will be switched to hydrogen gas, and its control rods will bring it up to full power for an exciting “hot-gas operation.”

The engine's skyward blast will contain a lot of escaping radioactivity, they expect. That's why they chose the remote Nevada site to try it out. As with bomb trials, Kiwi A's firings will await favorable winds—so that fallout will be carried



FIRST VIEW of Kiwi A rocket engine released by AEC (left) shows it on its car in firing position, at Test Cell Building, with locomotive waiting to tow it away. Artist's drawings show an A-propelled rocket in flight (above) and its engine (upper right) as visualized by engineers of Rocketdyne, which is working for Air Force on Project Rover. At right is photo of the radio-controlled, 15-ton "mine-type" locomotive, powered by batteries, that will haul test car bearing Kiwi A on standard-gauge railway track. It's designed for remote operation, including coupling to and uncoupling from test car, since—after a trial—the high-power, unshielded reactor will be too radioactive to approach.

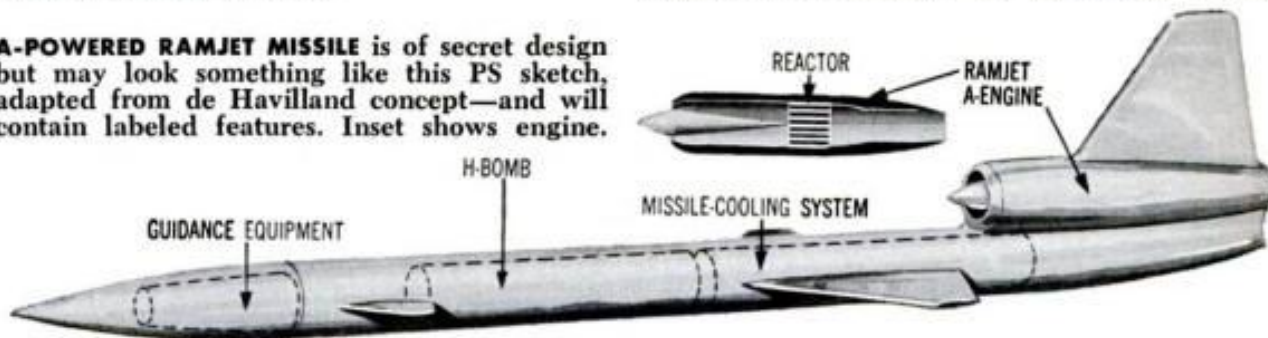


away from the test buildings, and won't make them uninhabitable.

What if Kiwi A should wreck itself and spill radioactive fission products all about? The worst that could happen, the experimenters foresee, is that they'd lose the test car—so radioactive that it might have to be buried. No one outside the test site need be worried; at most, the radioactivity would be a small fraction of what a one-kiloton A-bomb would release. Bombs regularly tested in Nevada have been much bigger.

Lest Kiwi A should prove a flop, or come to a violent end, they'll have an A-engine of alternate design ready for trial within about a year. Successive models of one type or the other will progress toward a flyable version.

A-POWERED RAMJET MISSILE is of secret design but may look something like this PS sketch, adapted from de Havilland concept—and will contain labeled features. Inset shows engine.



With a reactor ready, the Project Rover team must be well along toward solving its most staggering problem—of finding materials able to withstand a rocket reactor's heat of perhaps 4,000 degrees F. or more. At such heat, for example, fuel elements of uranium metal would melt; they may be using something like uranium carbide. Easing their problem a little, the materials needn't last long.

For a rocket, unlike other vehicles, can travel under A-power only a limited time—until the propellant's used up.

So an A-rocket's climb from earth may have a powered stage as brief as 300 to 400 seconds. Then the propellant tank will run dry. Deprived of the flow of gas that has been carrying its heat away, the engine will burn up—of "self-heat" from

Spacemen Come Down to Earth

DISTANT
PLANET

INTERPLANETARY
SPACE SHIP

LARGE SATELLITE
REFUELS SPACE
SHIPS. (ITS CREW
LIVES IN RIM.)

SATELLITE ORBIT — ALTITUDE
ABOUT 1,000 MILES

SPACE FERRY FLIES BETWEEN
AUXILIARY ORBIT AND ORBIT
OF LARGE SATELLITE, NEVER
ENTERING EARTH'S ATMOSPHERE

ECONOMY-SIZE SATELLITE SERVES
AS BASE FOR ASSEMBLING SPACE
FERRY. IT MAY THEN BE DISMANTLED,
OR KEPT IN USE AS OBSERVATORY, ETC.

MULTI-
STAGE
ROCKET
UNITS
GIVE
SUCCESS-
SIVE
BOOSTS
DURING
ASCENT

THIRD
STAGE

AUXILIARY ORBIT
ALTITUDE, 130
TO 150 MILES.
HERE CARGO IS
TRANSFERRED
FROM ROCKET TO
SPACE FERRY

SECOND
STAGE

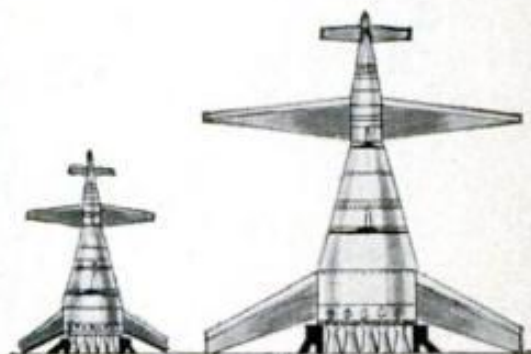
ROCKETS DELIVER CARGOES DIRECT
TO SPACE FERRIES AND RETURN TO
EARTH. TRANSFERRING CARGO RE-
QUIRES NO "SPACE PLATFORM"

FIRST
STAGE

EARTH

**Expert sees space station
possible in three years—
if built in easy stages.**

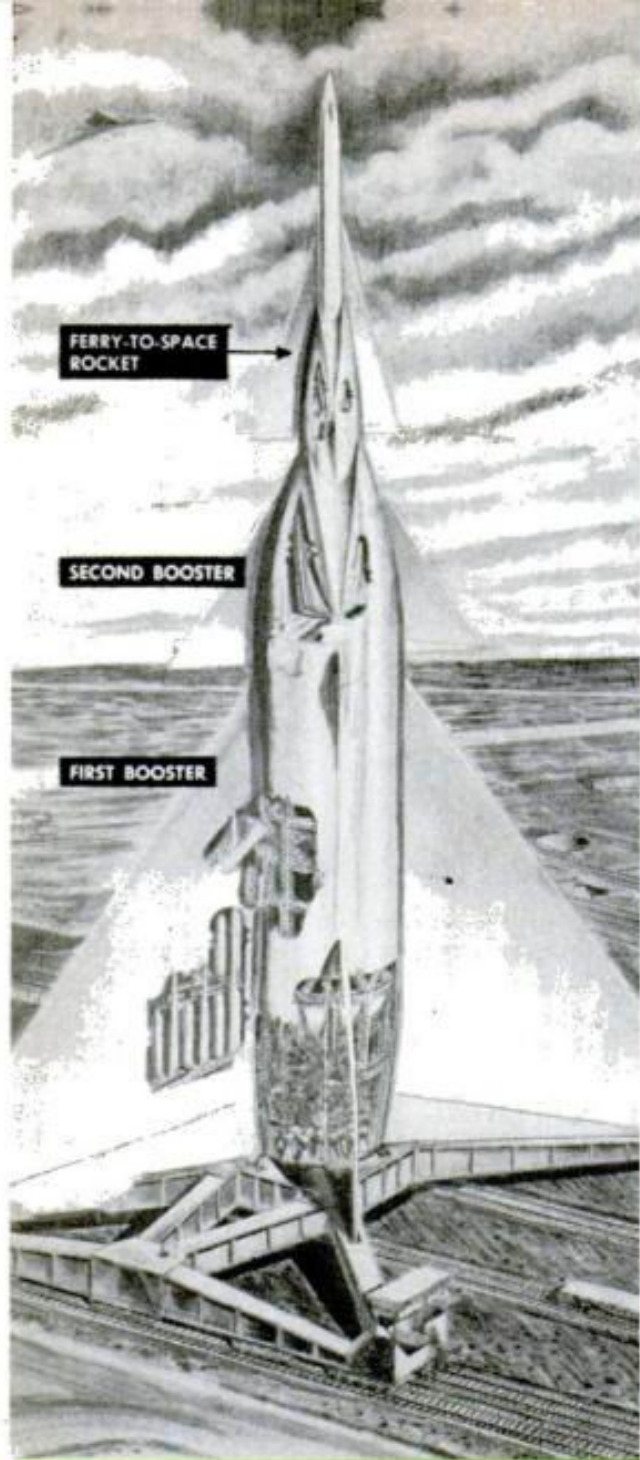
SPACE-VOYAGE enthusiasts dream of an artificial moon to refuel interplanetary craft. Far in the future are rockets that could deliver its materials direct from earth. But a guided-missile expert, Dr. H. A. Ehrlicke, has a way to begin sooner: 123-foot rocket ships, feasible "within the next three years," would carry cargo to an auxiliary orbit only 130 to 150 miles high. "Space ferries" assembled there would forward it to a satellite 1,000 miles up.



"FEASIBLE" 123-FOOT ROCKET (left)
compares with 210-footer needed
to reach satellite 1,000 miles up.

Tune Yourself

by Olin



THE booster rocket that got me off on a three-day space flight was an express elevator to the 24th floor of the Hotel McAlpin in New York City. Several hundred scientists and engineers were up there holding the ninth annual convention of the American Rocket Society.

Space-flight talk filled the air.

"I could blast you to smithereens the day you started building a station up in space," came a strident voice from a group in one corner.

"I'd do it like this," Strident Voice continued. "I'd let you send up hundreds of costly supply rockets with construction materials and equipment. I'd wait while you paid big overtime to hundreds of workmen floating around in space to put it together. I'd watch until you had spent your four billion dollars, or whatever—then I'd send up my homing rockets and blow your station to bits."

Strident Voice paused for breath, then added, "Anyway, that's what any enemy

Rocket planes riding tandem would keep space stations supplied

THREE-STAGE ROCKET pictured above would ferry men and supplies to a satellite station circling the earth 500 miles up in space. Each stage would carry a crew; delta wings would make it possible for all three to come back to earth in glider flight. On returning to earth, the two booster rockets would be fitted with jet engines for conventional airplane flight back to the take-off base. The top, or final, stage, would carry passengers and supplies to the space station. Picture at right shows details of construction, including rocket engines and rocket-fuel tanks in the wing. A design study for the space ferry was presented at American Rocket Society meeting by three engineers of the Goodyear Aircraft Corp.



Space-station enthusiasts are debating whether to build their own satellite or use one that's already circling Earth.



the Rocketmen

By Herbert O. Johansen

nation would do if we tried to build a big platform out in space."

"Suppose the space station were able to steer an evasive course when you sent up your space-station-blasting rockets?" a skeptic asked.

Lying in Wait—a Deadly Cloud

"Wouldn't make any difference," spoke up Strident Voice. "A direct hit isn't necessary. I could use the method proposed by Professor Thomas of Columbia for the destruction of satellite vehicles: fill the warhead of the rocket with several billion tiny pellets, or shot, and shoot it up into the orbit in the opposite direction of the artificial satellite. The warhead would explode and disperse the shot into a vast cloud through which the space platform would have to pass twice during each earth-orbiting. Before long the space station would be perforated into a lace station."

"But don't we all agree," a peacemaker asked, "that it would be a good

idea to have a manned space station?"

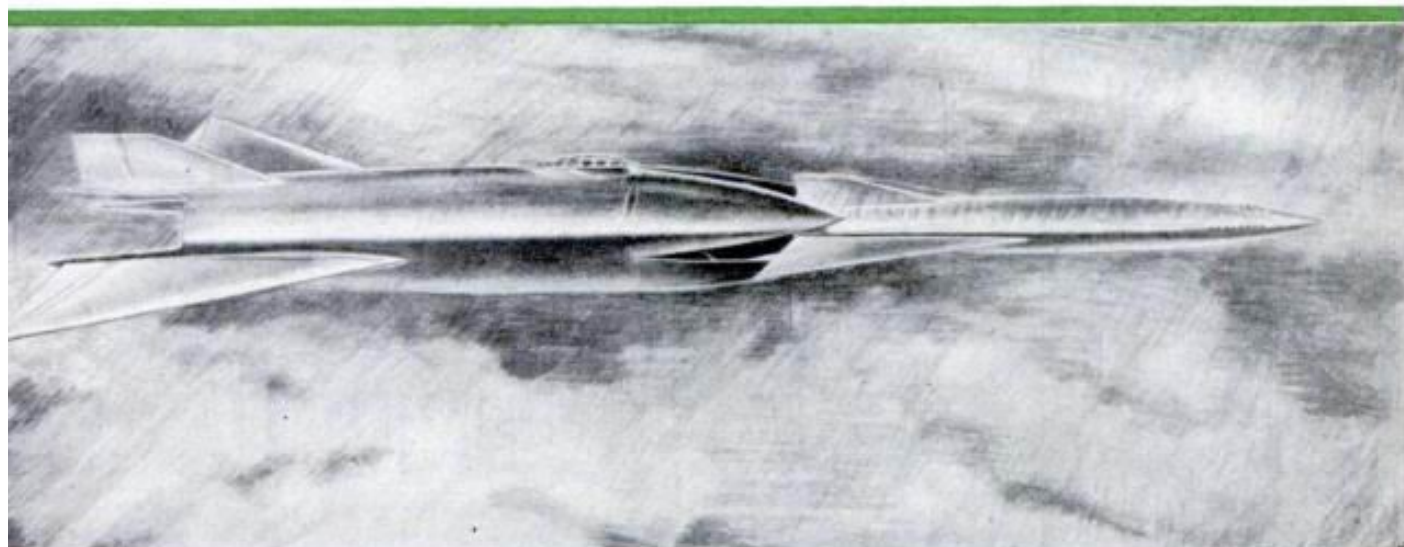
Everyone did. "Why, though," a gravelly voice asked, "do we have to build it? Couldn't we use a natural extra-terrestrial object, such as an asteroid, that's already circling the earth as a satellite? Then we would only have to send up supply ships with men and scientific equipment. A satellite of that size and mass—bigger than anything we could build—would be a Rock of Gibraltar in space. It just couldn't be destroyed."

"Yes, but we would have to find such a natural space body first," he was reminded.

He Looks for Tiny Worlds to Conquer

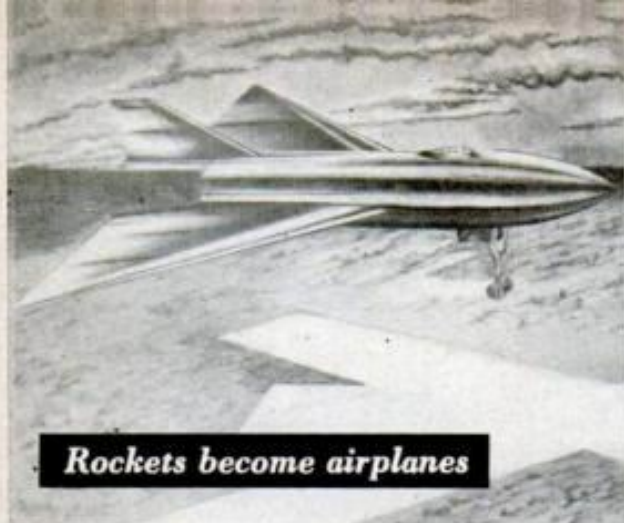
"I think our friend Dr. Tombaugh over there could take care of that for us. If his new telescope-camera can see a tennis ball 1,000 miles up in space, surely he would be able to find an asteroid that's big enough for us to colonize—if there is one up there, of course."

Gravelly Voice was referring to Dr.



WINGED ROCKET is shown at point where it would separate from the second booster at an

altitude of 40 miles. It would then speed on out into space at more than 15,000 m.p.h.

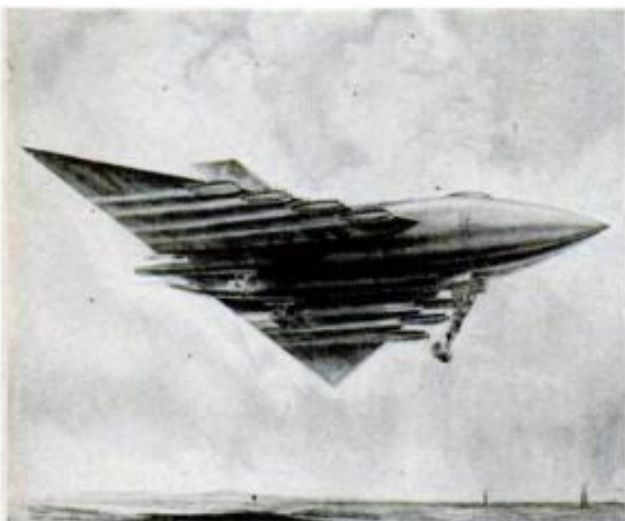


Rockets become airplanes

SECOND BOOSTER ROCKET, its landing gear lowered, makes a normal glide approach at an airport. The pilot would have some rocket fuel left for power flying in an emergency.



FITTED WITH JET-ENGINE PODS and added tail surfaces, the second booster takes off in conventional airplane flight for the return trip to its original take-off base.



FIRST BOOSTER is the giant of the space ferry. Here, fitted on first landing with four twin jet-engine pods on each side of its delta wing, it prepares to land at home base.

Clyde W. Tombaugh, the distinguished astronomer who discovered the ninth planet, Pluto, in 1930. He is now in charge of a satellite search for Army Ordnance at White Sands Proving Ground in New Mexico.

Whether his camera has picked up anything of significance, Dr. Tombaugh will not say. But he believes that "the chances that there are such natural earth satellites are just as good as the chances that there aren't any."

I moved on to another group, attracted by the startling remark: "We must have a regular, dependable and safe passenger-cargo rocket-ferry service into space—perhaps daily—if we expect to have a permanently manned station."

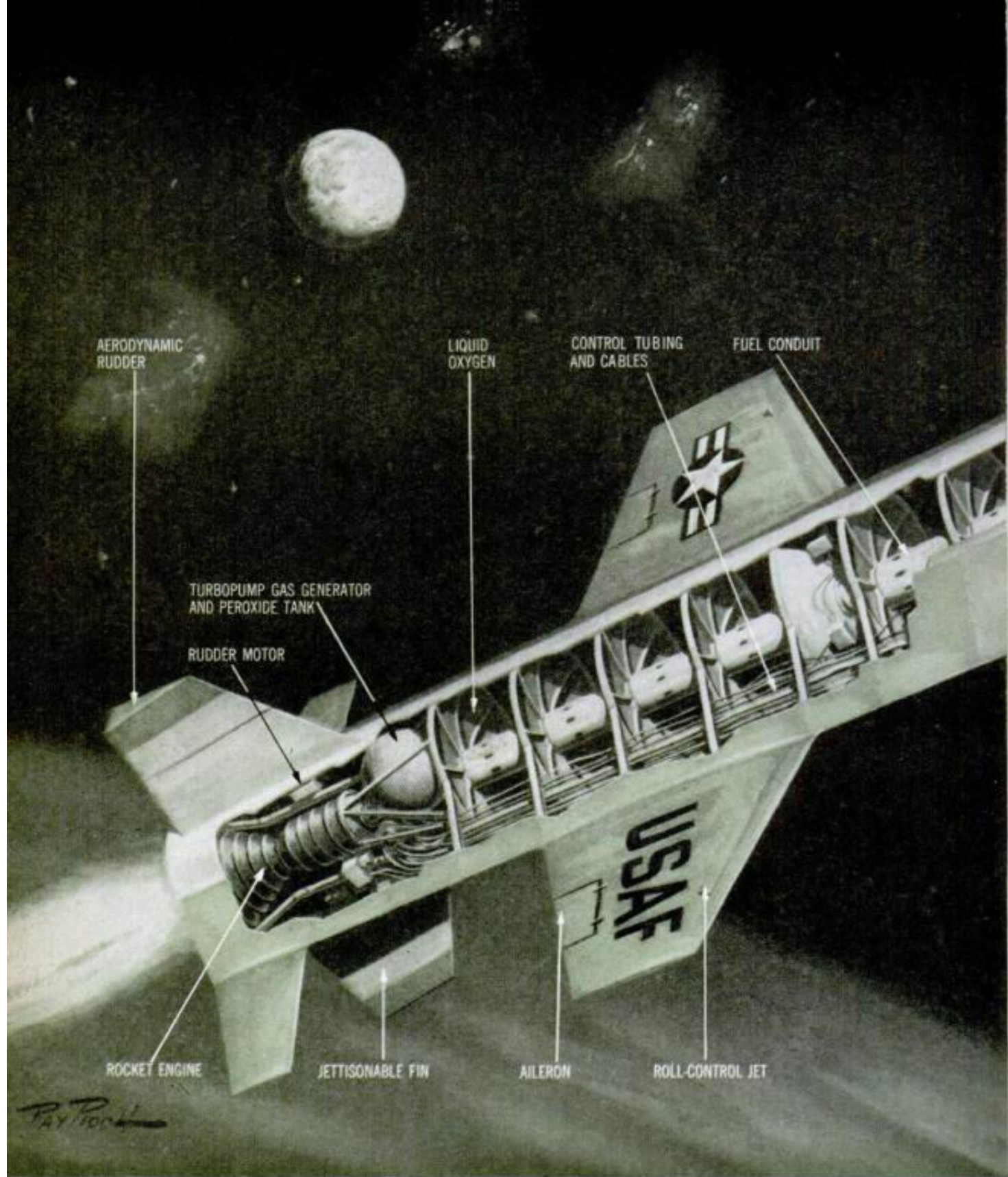
"How about the Romick-Knight-Van Pelt system?" another speaker suggested. "Their winged glider-boosters sound very practical."

I soon heard more about this Romick-Knight-Van Pelt system from Darrell C. Romick of the Aerophysics Department of the Goodyear Aircraft Corp. His contribution to the meeting was a paper, prepared in conjunction with Richard E. Knight and John M. Van Pelt, also Goodyear engineers, outlining a plan for a space-station ferry service. Theirs is the plan pictured on these pages.

A 500-Mile Hitchhike—Straight Up

The vehicle they propose would stand 285 feet high and be made up of three rockets. Each stage would have airplane delta wings, extendible landing gear, and carry a crew. The second (center) booster rocket would nestle between open doors in the nose of the bottom rocket. The top rocket would snuggle into the open doorway of the second stage. Total weight would be 9,000 tons, of which 7,807 tons would be rocket fuel. The top rocket would carry 35 tons of passengers and cargo 500 miles above the earth for its rendezvous with the orbiting space-station satellite.

For a take-off base, they suggest the Army's White Sands Proving Ground in New Mexico. When the first stage fired, it would boost the monster rocket pyra-

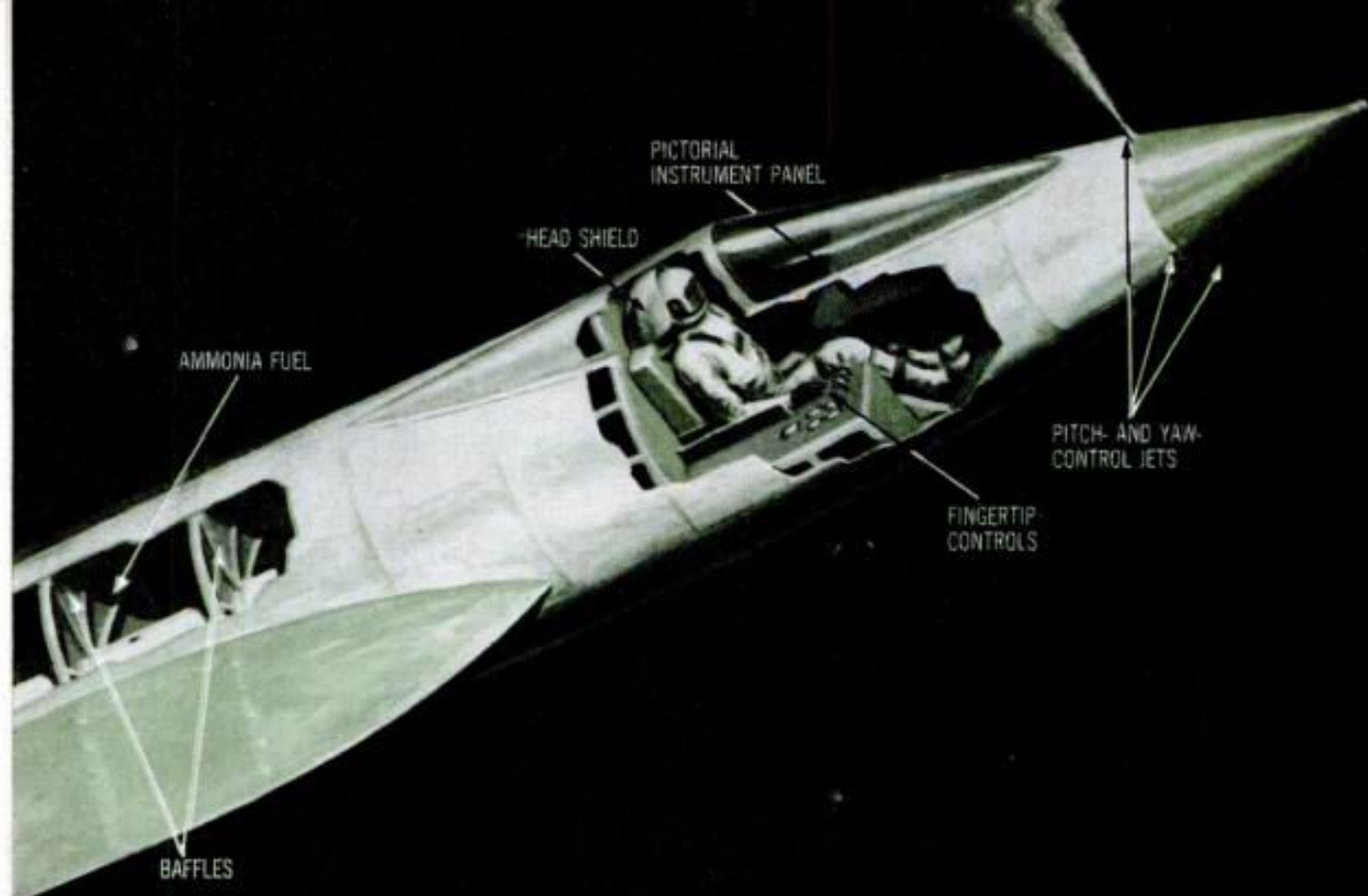


A stubby-winged "missile with a cockpit," the X-15 will take its pilot to the edge of space—and open a new era of flight

By Wesley S. Griswold

THE most extraordinary airplane in the U. S., and probably the world, is now taking shape in a closely guarded Los Angeles factory.

The X-15 is a research craft as far in advance of today's hottest fighters as they, in turn, exceed the Wright Brothers' powered box kite. It is intended to fly scores of miles higher and at least 2,000 m.p.h. faster than any plane now in the



Mile-a-Second Rocket Plane Will Fly 100 Miles High

sky. The men who first fly it will take a tentative dip in the mysterious sea of outer space before future men plunge in.

Still months away from trying its stubby wings, the revolutionary X-15, a manned rocket ship, has already stirred international excitement.

It has been grandly heralded as "a steppingstone to the stars." But the men

who designed it, the technicians who are building three of it, and the test pilots at Edwards Air Force Base who will find out just how high and how fast it can go have less poetic names for this up-and-coming wonder. They call it "the flying fuel tank" or "the missile with a cockpit."

Only one official statement has been made so far about what the X-15 will do,

JUNE 1958 III

GREEN SKIES AT

This hydrogen-burning hypersonic airliner could fly more than twice as fast as the 1,350mph Concorde—and its passengers would travel absolutely guilt-free

BY MICHAEL BELFIORE ILLUSTRATION BY NICK KALOTERAKIS

MODERN AIR TRAVEL is a marvel. It's also a source of endless delay, annoyance and planet-killing greenhouse gases. A proposed hydrogen-powered hypersonic airliner could change all that. The plane is Reaction Engines's A2 concept, a Mach-5 (3,400mph) craft for 300 passengers funded in part by the European Union's Long-Term Advanced Propulsion Concepts and Technologies project (Lapcat). Lapcat wants an airliner that can fly from Brussels to Sydney in less than four hours. If built, the A2 will do just that—without producing a trace of carbon emissions.

Engineers created the A2 with the failures of its doomed supersonic predecessor, the Concorde, very much in mind. Reaction Engines's technical director, Richard Varvill, and his colleagues believe that the Concorde was phased out because of a couple major limitations. First, it couldn't fly far enough. "The range was inadequate to do trans-Pacific routes, which is where a lot of the potential market is thought to be for a supersonic trans-

port," Varvill explains. Second, the Concorde's engines were efficient only at its Mach-2 cruising speed, which meant that when it was poking along overland at Mach 0.9 to avoid producing sonic booms, it got horrible gas mileage. "The [A2] engine has two modes because we're very conscious of the Concorde experience," he says.

Those two modes—a combination of turbojet and ramjet propulsion systems—would both make the A2 efficient at slower speeds and give it incredible speed capabilities. (Engineers didn't include windows in the design because only space-shuttle windows, which are too heavy for use in an airliner, can withstand the heat the A2 would encounter.) In the A2's first mode, its four Scimitar engines send incoming air through bypass ducts to turbines. These turbines produce thrust much like today's conventional jet engines—by using the turbine to compress incoming air and then mixing it with fuel to achieve combustion—and that's

enough to get the jet in the air and up to Mach 2.5. Once it reaches Mach 2.5, the A2 switches into its second mode and does the job it was built for. Incoming air is rerouted directly to the engine's core. Now that the plane is traveling at supersonic speed, the air gets rammed through the engine with enough pressure to sustain combustion at speeds of up to Mach 5.

That's the principle behind all ramjet designs. But the Scimitar's system goes further by adding a turbine compressor that squeezes air even more intensely. This is a big departure from traditional ramjet design; these air-breathing engines normally can't use turbines because the air enters the

GREEN FUEL

The A2 runs on liquid hydrogen, which produces water vapor and a small amount of nitrous oxide as exhaust and is energy-dense enough to fly this plane all the way from Brussels to Sydney. To be truly green, however, the A2 must use hydrogen produced in a carbon-neutral process such as electrolysis powered by a nuclear, solar or biofuelled power plant.



MACH 5

engine at such a high temperature—1,800°F at Mach 5—that turbine blades would quickly melt. In the Scimitar, though, a cooling system wrapped around the inside of the engine cools incoming air enough to let it run through a turbine. As a result, the A2 has a setting for every speed.

But an even greater asset than the A2's speed is its negligible carbon footprint. It's hydrogen-

powered, so it produces only water vapor and a little bit of nitrous oxide as exhaust.

And although a hypersonic jet loaded with liquid hydrogen might sound dangerous, hydrogen fuel is actually no more explosive than normal jet fuel.

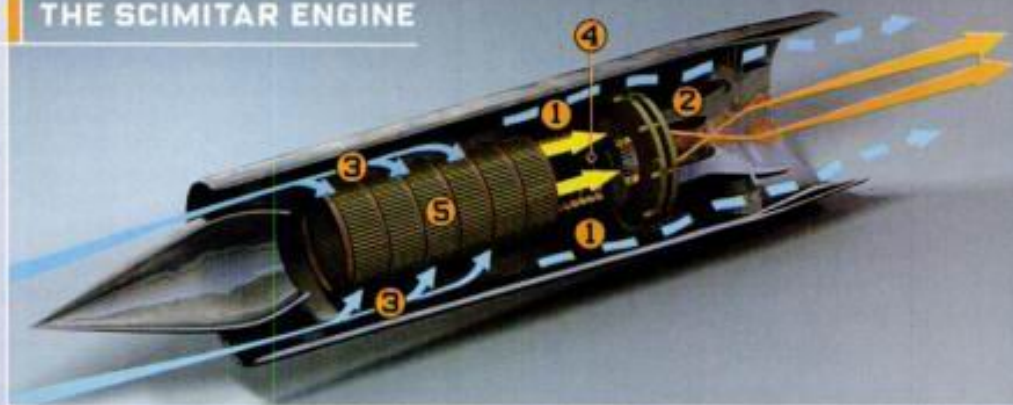
Joseph Schetz, a hypersonic-propulsion expert at Virginia Tech, says there's nothing fundamentally unsound in the A2's plans, "but whether it's doable or not is a whole other conversation." The engineers still face crucial design obstacles, such as building heat exchangers reliable enough for hypersonic flight.

The biggest challenge: manufacturing hydrogen fuel on a large scale without emitting carbon in the process. Indeed, Varvill is hesitant to pitch his plane as a truly green machine because he believes carbon-free hydrogen production is still a long way off. If a viable hydrogen economy comes to pass, though, the A2 could very well be the new airliner of choice.

NO WINDOWS

No commercially viable aircraft windows can survive hypersonic flight, so for now, the A2 design features an unbroken hull. Studies show that people don't like to fly in planes with no windows—but they might change their mind when they learn that the A2 cuts a 22-hour flight down to four hours.

THE SCIMITAR ENGINE



For takeoff, landing and subsonic flight, the A2's Scimitar engine sends intake air through a bypass duct [1] and into a turbine [2], like a standard jet engine. After reaching supersonic speed, though, the engine redirects air from the bypass duct through the engine core [3] for flight

up to Mach 5. Like a ramjet, the Scimitar works by taking in air from the atmosphere at high speeds and funneling (or "ramming") it until it's intensely compressed. At this point, the extremely hot air mixes with fuel and causes ignition. But the Scimitar one-ups traditional ramjet design by

adding a turbine [4] that compresses the incoming air even further. Ramjets usually can't use turbines because the incoming air is so hot that it will melt the turbine blades. The Scimitar solves that problem by first cooling the air in a heat exchanger [5] using gaseous helium.

SPACE TECH

THE BUDDY SYSTEM

For astronauts on the ISS, a new robot means fewer risky spacewalks

REPLACING A CIRCUIT BREAKER In a dark basement is one thing. But what if you had to climb around the outside of a spacecraft orbiting hundreds of miles above the Earth to do it? This kind of dangerous maintenance work has become fairly common for astronauts aboard the International Space Station, where they spend as much time fixing the \$100-billion-plus orbiting science lab as they do performing actual research.

Fortunately, help is scheduled to arrive this month in the form of the Special Purpose Dexterous Manipulator, or Dextre, a versatile, \$200-million robotic handyman that will perform many of the station's mundane tasks and reduce the number of death-defying spacewalks.

The two-armed robot, built by the Canadian Space Agency (CSA), is the final component of the station's Mobile Servicing System. The system includes a base, already installed, that can traverse the length of the station carrying a 55-foot-long robotic arm called Canadarm2. Dextre, which can attach to the

end of that arm, consists of a rotating torso and two multijointed limbs that let it approach a job from any angle. Each arm ends with a vice-grip clasper that locks onto handles strategically placed on the outside of the station.

Future tools will expand Dextre's skill set [see "Dextre's Toolbox," below], but the robot arm may never be capable of assignments that demand on-the-fly problem solving, such as November's repair to a torn solar array. (Perhaps the most dangerous spacewalk in history, the mission required astronaut Scott Parazynski to lock his feet to the end of a long boom, travel a record-setting distance from the airlock, and jury-rig a patch on solar panels coursing with more than 100 volts of electricity.)

Although Dextre won't eliminate risky spacewalks, Daniel Rey, the lead CSA engineer on the project, says that it will limit unnecessary risk. "In such a hazardous environment," he says, "if a robot can do the task, then it should be doing the task."—GREGORY MONE

REPAIR

The vice-grip clasper on the end of Dextre's free arm will lock onto remote power-control modules—which act like circuit breakers—removing old ones and inserting replacements.



DEXTRE'S TOOLBOX



SARAH (Self-Adaptive Robotic Auxiliary Hand) Now, Dextre's simple gripper attaches to only certain places on the ISS. Sarah, a three-fingered gripper designed by CSA engineers at Laval University in Quebec, will allow it to grab a variety of handles.



BMT (Blanket-Manipulation Tool) The ISS uses Velcro-attached thermal blankets to keep external components from getting too hot or cold. The Blanket-Manipulation Tool, another Laval project, could help Dextre to replace or adjust them.

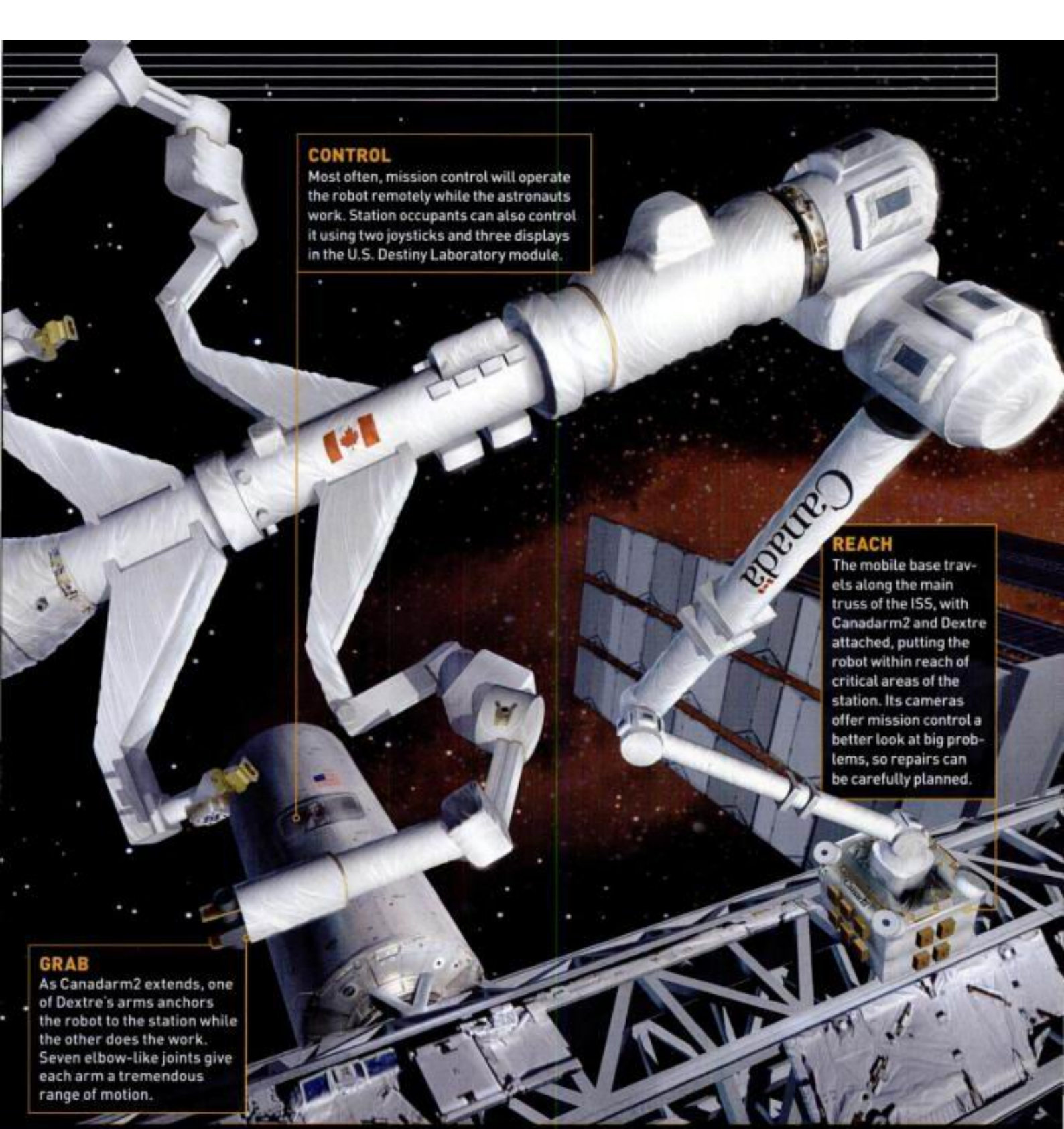
investigate the use of alternative jet fuels, including butanol blends [see "Fly the Eco-Friendly Skies," page 40]. Gregory Stephanopoulos, a professor of chemical engineering at the Massachusetts Institute of Technology who researches biofuels, says, "The real challenge is to make organisms that can tolerate butanol."

BP and DuPont aim to do just that by

2010. In the meantime, the companies are busy preparing for the biofuel boom, building the first-ever butanol demonstration plant, in England. By late 2009, the plant will turn out about 5,000 gallons of butanol every year, initially all from locally grown crops. Soon after, the team plans to convert an ethanol plant in the same complex.

Of course, there's a huge market for

effective alternative fuels, both to meet the growing demand for automotive fuel—expected to increase by more than 25 percent by 2030, even as traditional oil reserves are depleted—and to find fuels that release fewer greenhouse gases into the atmosphere. The Department of Energy has promised to spend more than \$1 billion on biofuel research over the next few years.



CONTROL

Most often, mission control will operate the robot remotely while the astronauts work. Station occupants can also control it using two joysticks and three displays in the U.S. Destiny Laboratory module.

REACH

The mobile base travels along the main truss of the ISS, with Canadarm2 and Dextre attached, putting the robot within reach of critical areas of the station. Its cameras offer mission control a better look at big problems, so repairs can be carefully planned.

GRAB

As Canadarm2 extends, one of Dextre's arms anchors the robot to the station while the other does the work. Seven elbow-like joints give each arm a tremendous range of motion.

Butanol is easier to transport than existing biofuels, and it has an energy content closer to that of gasoline.

But although American biofuel use has more than doubled since 2003—to 5.6 billion gallons per year, or 2.6 percent of total consumption—today's alternative fuels are far from ideal. Our ethanol and biodiesel supplies are derived completely from food crops, such as corn and soybeans. They require large amounts of land and water to grow. Far better is the pos-

sibility of producing fuels from cellulose, like cornstalks and other plant refuse.

DuPont, among others, is working on engineering enzymes that will enable that process for both ethanol and butanol. "The solutions definitely exist today to change the transportation-fuel mix," Ranieri says, "and to do it much more quickly." —KALEE THOMPSON

THE WORLD'S BIGGEST TELESCOPE

About half the size of a football field and 21 stories tall, the largest optical telescope ever constructed will use almost 1,000 mirrors to hunt for exoplanets—and maybe even unlock the secrets of spacetime **BY BJORN CAREY**

HOW TO CAPTURE THE COSMOS

1. COLLECT THE LIGHT

Starlight hits the 138-foot-wide parabolic **PRIMARY MIRROR**—an array of 984 hexagonal panels, each one 330 pounds, 4.8 feet in diameter and two inches thick. The panels are so heavy that gravity actually causes them to shift very slightly as the scope moves, so three actuators under each panel flex 10 times per second to keep the mirror properly aligned. The light bounces up to the 20-foot-wide **MIRROR A**.

2. REFLECT IT

MIRROR A reflects and inverts light through a hole in **MIRROR C** onto the 13.8-foot **MIRROR B**, which directs light up to the reflective surface of **MIRROR C**.

3. SHARPEN IT

MIRROR C is a thin two-millimeter glass shell stretched over 5,000 actuators that

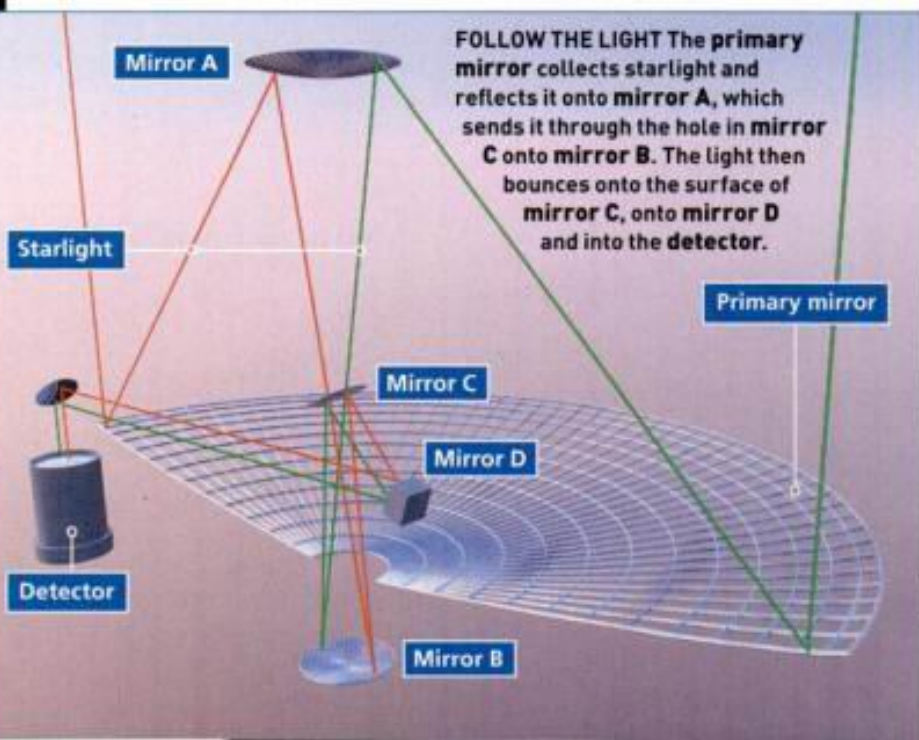
push or pull to reshape the mirror's surface 1,000 times per second. This rapid action performs so-called adaptive optics—realigning light distorted by the atmosphere into a sharp image. Astronomers calculate the correct setting for this mirror using bright reference stars [see "Calibrating a Giant Scope," right].

4. SEND IT TO A SENSOR

Once corrected by the adaptive optics system, the light hits **MIRROR D**, 8.9 feet in diameter, which moves up to 20 times per second to keep the reference star aligned against vibrations from wind hitting the structure. This mirror reflects the starlight to a **DETECTOR**, which houses a camera that captures images, and to instruments that astronomers use to measure such phenomena as the speed at which the universe is expanding.

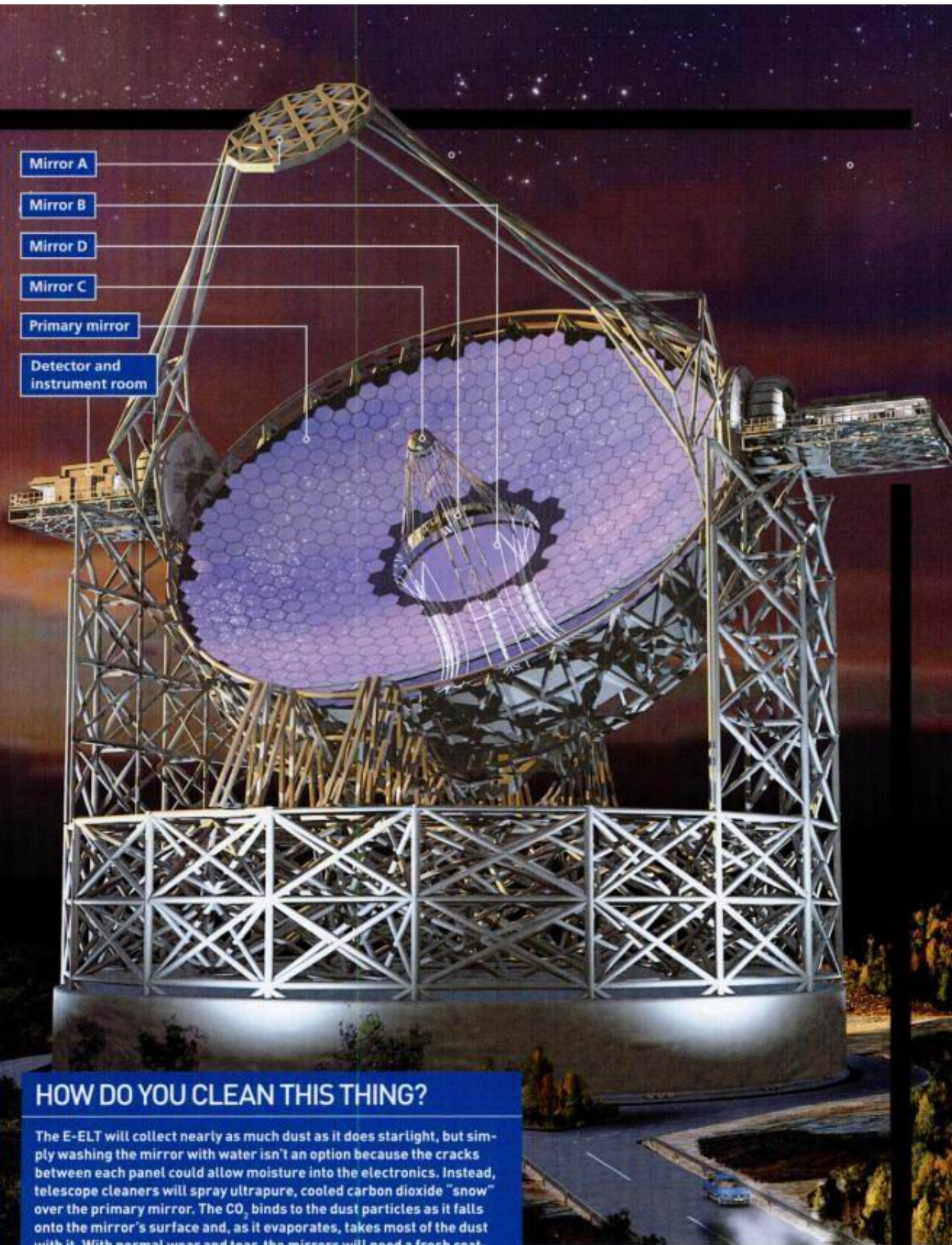
CALIBRATING A GIANT SCOPE

Atmospheric turbulence and airborne particles scatter starlight as it heads toward ground-based telescopes, so astronomers calibrate the European Extremely Large Telescope's optics using bright reference stars in the same field of view as the target object. The rippled light wave hits each pixel on mirror C at slightly different times. The adaptive optics system morphs the mirror's surface so that the light hits each pixel at the same time, creating a clear image. But if an object has no nearby stars, astronomers make their own reference stars: Five or six lasers, known as a laser guide-star system, excite sodium ions 56 miles up in the atmosphere to create artificial beacons.



THE EUROPEAN EXTREMELY LARGE TELESCOPE (E-ELT)

BUILT BY: European Southern Observatory
SITE SELECTION: Will choose site by late 2008, probably in the Southern Hemisphere
CONSTRUCTION STARTS: Early 2010
FULLY OPERATIONAL: 2017
DESIGN COST: \$81.3 million
CONSTRUCTION COST: \$1.1 billion
IMAGE RESOLUTION: 10–15 times as sharp as Hubble
PRIMARY MIRROR: 138 feet wide
NEXT BIGGEST SCOPE: The Gran Telescopio Canarias in the Canary Islands (34 ft.) and the Thirty Meter Telescope (98 ft.), scheduled for completion in 2016 (site undetermined)



Mirror A

Mirror B

Mirror D

Mirror C

Primary mirror

Detector and
instrument room

HOW DO YOU CLEAN THIS THING?

The E-ELT will collect nearly as much dust as it does starlight, but simply washing the mirror with water isn't an option because the cracks between each panel could allow moisture into the electronics. Instead, telescope cleaners will spray ultrapure, cooled carbon dioxide "snow" over the primary mirror. The CO_2 binds to the dust particles as it falls onto the mirror's surface and, as it evaporates, takes most of the dust with it. With normal wear and tear, the mirrors will need a fresh coating of reflective material, most likely aluminum, every few years.



Boeing could produce.) Efficiency is the critical challenge: Airlines won't buy a new airplane unless it costs less to fly than the aircraft they already own. "The A380 has to offer 15 to 20 percent better seat-mile costs to justify the investment," says Rob Bray, the A380's lead wing engineer.

To deliver that performance, Airbus has put several new technologies to work. It employed computational fluid dynamics (CFD) far more sophisticated than previous-generation CFD. The new programs can handle especially complex behavior, such as the airflow between the wing and the engine nacelle, an area prone to drag problems. Also, new stereolithography techniques, which turn computer designs into solid resin objects, generated wind tunnel models from the CFD designs overnight, permitting more of what Bray calls "What if we could?" exercises.

A380 chief engineer Robert Lafontan notes that commercial aircraft design has long been highly refined, however, so the efficiency game is always one of small percentage gains. Airbus had to rely on new materials and new ways of using existing materials to boost the advantage. The A380 is the first airliner to use a center wing box—which joins the wings to the body—made mostly from carbon-fiber composite material. At 22,000 pounds, the wing box is a ton lighter than a metal equivalent.

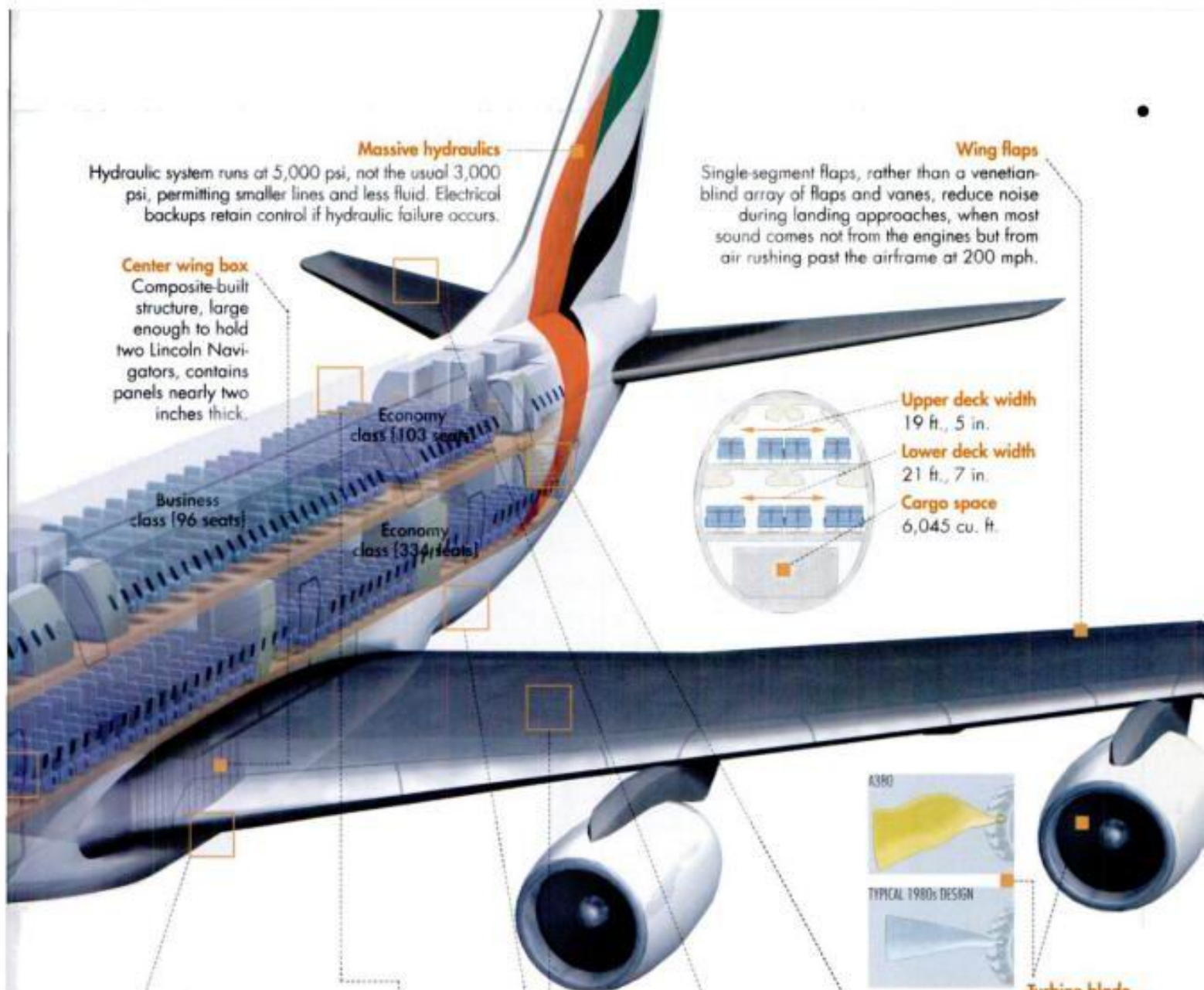
Still, classic airplane metals are far from being phased out. New alloys and assembly methods for metals are evolving quickly. Instead of using rivets to assemble aluminum wing ribs, Airbus employs massive Makino high-speed machine tools in its factory near Bristol, England. Cutting heads turn a 13-by-6 foot, 2.5-ton slab of aluminum alloy into a complete wing rib in half a day. Some of the A380 ribs are efficient, ultralight open frames that can only be made with this new technology.

The aircraft's engine designers were pressured to deliver efficiency and power but also discretion, especially after Singapore Airlines, in 2000, challenged Boeing and Airbus to make their airplanes exceed the stiff noise standards at London's Heathrow airport, Europe's biggest gateway to Asia. (Heathrow grants more takeoff and landing slots to quiet airplanes, and, at the time, Boeing was pitting a hypothetical 747X against the [\[CONTINUED ON PAGE 134\]](#) ▶

[THE SPECS]

	A380	747-400	737-800
MAX. TAKEOFF WT.	1,235,000 lb.	875,000 lb.	174,200 lb.
TAIL HEIGHT	79 ft.	64 ft.	41 ft.
TYPICAL SEATING	555	416	162
TYPICAL CRUISING SPEED	630 mph	567 mph	530 mph
RANGE	9,206 mi.	8,354 mi.	3,893 mi.





Massive hydraulics

Hydraulic system runs at 5,000 psi, not the usual 3,000 psi, permitting smaller lines and less fluid. Electrical backups retain control if hydraulic failure occurs.

Center wing box

Composite-built structure, large enough to hold two Lincoln Navigators, contains panels nearly two inches thick.

Business class (96 seats)

Economy class (103 seats)

Economy class (334 seats)

Wing flaps

Single-segment flaps, rather than a venetian-blind array of flaps and vanes, reduce noise during landing approaches, when most sound comes not from the engines but from air rushing past the airframe at 200 mph.

Upper deck width

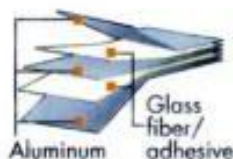
19 ft., 5 in.

Lower deck width

21 ft., 7 in.

Cargo space

6,045 cu. ft.



Aluminum

Glass fiber/adhesive



A380

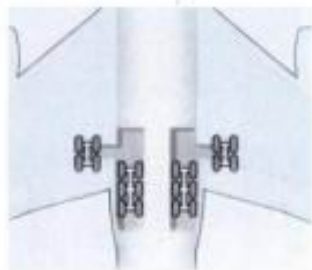
TYPICAL 1980s DESIGN

Turbine blade

Heavily sculpted fan blades push more air through equal-diameter engine inlets, increasing engine efficiency.

HEAVY GEAR

The A380's 20-wheel main landing gear weighs 20 tons despite its lightweight alloys. Airbus built mock-ups to prove that the gear could be steered around tight taxiways and that it would not damage runways.



SKIN LAYERS

Upper-body skin panels—usually susceptible to metal fatigue and cracking due to the stress of pressurization and aircraft weight—are made from a material called Glare (from "glass reinforced"), which comprises 0.5-millimeter-thick sheets of aluminum sandwiched around layers of strong, crack-resistant S-glass fibers.

NEW ALLOY

The aircraft uses new, stronger aluminum alloys in its upper-wing skins. The panels, up to 115 feet long, are carved from solid billets and formed into shape by air pressure in a 430°F autoclave. In the lower fuselage, where fluids can accumulate and cause corrosion, the skins are made from another new aluminum alloy, which can be welded with a laser, eliminating holes.

ARTIFICIAL STABILITY

The A380 will be the first commercial airplane to fly with its center of gravity close to the wing's center of lift. The horizontal tail will provide lift to keep the airplane's nose down, rather than a downforce—which adds drag—to keep the nose up. Computers will keep the airplane stable and help move the control surfaces based on pilot inputs.

FULL DOUBLE-DECKER

Airlines requiring high-density arrangements can have 820 seats, nine abreast on the upper deck and 11 abreast on the main deck. This gives a lower operating cost per seat, but also less space per passenger, than the standard 555-seat arrangement. Other configurations will permit such amenities as lounges, retail space and business centers.



A proposal
to transform
the **F-22 Raptor**
into a high-altitude,
first-strike
smart bomber
illustrates
a harsh
reality of
today's warfare:
The U.S. bombing
fleet is
ill-prepared
to fight wars in regions that are short on friendly nations willing to



WART BOMBER

lend air bases.

By Bill Sweetman
ILLUSTRATIONS BY JOHN MACNEILL

Материал опубликован авторским изданием

TURNING A FIGHTER INTO a bomber may seem like trying to convert a Honda S2000 roadster into a pickup truck. Fighters, which are designed to dogfight with hostile airplanes and perform short-range attack missions, are fast and agile; bombers are made to haul heavy loads for thousands of miles. But Lockheed Martin is designing a fighter-bomber hybrid based on the F-22 Raptor fighter that's in flight-testing at Edwards Air Force Base in California. The proposed bomber variant—informally known as the FB-22—has been attracting increasing interest since the September 11 attacks and the start of U.S. operations in Afghanistan.

Before Afghanistan, the Air Force considered its current fleet of bombers adequate and had no plans to build new ones until the late 2030s. In the 1991 Persian Gulf War, after all, B-52s—slow and as unstealthy as battleships but loaded with more than 30,000 pounds of guided bombs—were successfully deployed against both ammunition dumps and front-line troops. A few heavy airplanes, the Air Force reasoned, went a long way.

But then came the mission against the Taliban and Al Qaeda, and Air Force leaders realized how sorely the service had been neglecting its bomber fleet. Whereas in the Gulf War, the United States could launch its planes from the territory of a nearby ally, Saudi Arabia, Afghanistan was a long way from any country that felt like playing host to U.S. combat aircraft. B-52 and B-1 bombers cruised to Afghanistan from British-owned Diego Garcia in the Indian Ocean, but it took them so long that they could fly fewer missions than desirable. And as tensions continue to rise in the Middle East, nations that are capable of providing the United States with bases within range of likely war zones are coming under increasing pressure, both from terrorists and from their discontented populations, not to do so. Meanwhile, U.S. bombers are aging: The newest B-52 is 40 years old, and the B-1 is a complex, maintenance-heavy plane designed in the early 1970s. Many military experts believe it's time to revitalize the worn-out bomber fleet.

The FB-22 could be the answer. A midsize bomber, it would inherit the F-22's ability to fly higher and faster than other comparable planes—up to 1,200 mph at 60,000 feet—but

FROM FIGHTER TO BOMBER

The F-22 Raptor, the world's first stealth air-to-air fighter, will enter service with the U.S. Air Force in late 2005. But with a few shrewd adjustments, the F-22 could be converted to a bomber—the FB-22—a plane that would travel farther and carry a complement of efficient smart bombs for ground strikes. Here's how it could be done.

RANGE: 900 miles
WEIGHT: 32.7 tons

TOP SPEED: Mach 2.0
DEPLOYMENT: 2005

F-22

FIGHTER



44 ft. 6 in.



62 ft. 1 in.

Weapons

Main weapons bay holds six radar-guided medium-range air-to-air missiles (AMRAAMs); each side bay fires a heat-seeking Sidewinder missile that homes in on an enemy plane's exhaust.

Cockpit

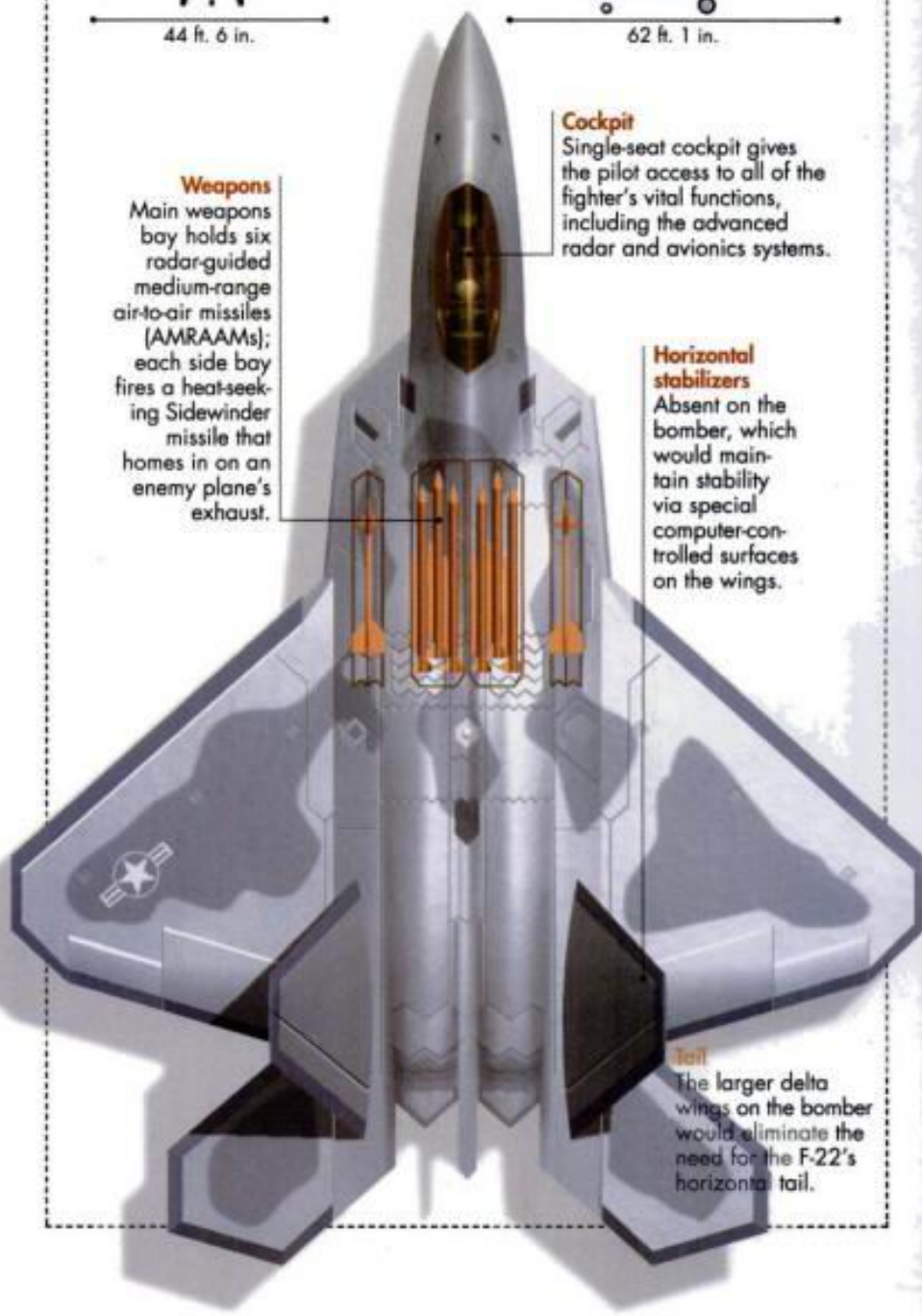
Single-seat cockpit gives the pilot access to all of the fighter's vital functions, including the advanced radar and avionics systems.

Horizontal stabilizers

Absent on the bomber, which would maintain stability via special computer-controlled surfaces on the wings.

Tail

The larger delta wings on the bomber would eliminate the need for the F-22's horizontal tail.



would have longer legs and a bigger weapons load. Moreover, it would be a perfect fit with one of the Air Force's most promising new weapons, the Small Diameter Bomb. Though it's a fraction of the weight of a standard bomb, this new bomb is exceedingly precise, thanks to a satellite-controlled GPS-guid-

FB-22

FIGHTER BOMBER

RANGE: 2,200 miles

TOP SPEED: Mach 1.8

WEIGHT: 42.5 tons

DEPLOYMENT: 2015 (est.)



46 ft. 0 in.



64 ft. 0 in.

Delta wing

The longer, thicker delta wing would enable the FB-22 to carry up to 80 percent more fuel than the F-22, giving it a correspondingly greater range. The larger profile would also help the FB-22 lift its added weight at lower speeds.

Inlets

A bulge in the air inlets—a stealthy design detail borrowed from the Joint Strike Fighter—would divert turbulent air away from the engines.

Weapons

Main weapons bay, stretched by 12 feet, would hold 24 Small Diameter Bombs; each side bay would hold an AMRAAM for self-defense against other planes.

Engines

Two new engines—either GE's F136 or Pratt & Whitney's F135, both of which were designed for the Joint Strike Fighter.

Body

Fuselage would be lengthened by 10 feet.

Air Force Chief of Staff Gen. John P. Jumper is enthusiastic about the idea of putting bombs on the normally missile-bearing F-22—a measure that could be considered an interim move toward the FB-22. When the U.S. Army "talks about putting capabilities deep behind enemy lines, this is the thing that will be able to come in at Mach 1.5 to 1.7 to deal with any trouble that they might run into," Jumper says of the F-22, which is scheduled to debut with the Air Force in 2005. "This will be the airplane that nothing can touch. This is transformational."

But there are signs of controversy within the Air Force over the notion of morphing the F-22 for a new mission. Air Force Secretary James G. Roche has taken a serious interest in the plane, but others, including Chief of Staff Jumper, are far from sold. These skeptics suggest the FB-22 offers little that's new, because the F-22 itself can carry Small Diameter Bombs (albeit not as many), and its range could be augmented by aerial refueling. This view is unlikely to sway Roche, who already frets publicly about the Air Force's dependence on aging tanker planes, but the debate itself is telling. The atmosphere within U.S. military circles these days is tense. Faced with unprecedented new threats, officials know they must adjust their strategies and tools. Whether or not it's ever built, the FB-22 offers insight into the changing nature of warfare and the need for relatively quick (in weapons-development terms) and economical responses.

The design of the FB-22 is still hush-hush—Lockheed Martin considers it "proprietary" and has not released any artists' concepts—and as the company responds to shifting military priorities, the details are bound to change. Still, Lockheed officials have said enough to make it possible to make some broad predictions about the proposed plane. For starters, the FB-22 would have a triangular "delta" wing instead of the F-22's more standard ones. The delta wing would be larger—a necessary modification because bombers must be capable of striking ground targets wherever those targets happen to be, and so they must have

significant range. To fly farther, the FB-22 needs to carry more fuel, and wings are the best place to store it. Delta wings are long from front to back and so can be much deeper; they also have a larger area, so their volume is greater. The FB-22 would carry as much as 80 percent more fuel than the F-22.

ance system. The FB-22, which would be built to carry 24 Small Diameter Bombs, could be the ideal aircraft for the warfare of the future. And since it's based on an existing design and would share many parts and materials with its predecessor, it would be relatively inexpensive to build.

POWER WARS: VIPER, PORSCHE, LAMBO, BENTLEY + THE POPSCI POWER LIST

POPULAR science



THE TECH OF
MINORITY
REPORT'S SCI-FI
LEXUS P. 28

SMART
BOMBS
FROM

DESIGNING
A FAST,
HIGH
BOMBER
FOR A NEW
FIRST-STRIKE
MISSION

FB-22 DELTA WING VERSION
OF THE RAPTOR

60,000 ft.

Privacy in Peril

Who's Scanning
Your Digital DNA
GPS Phones Know
Where You Are



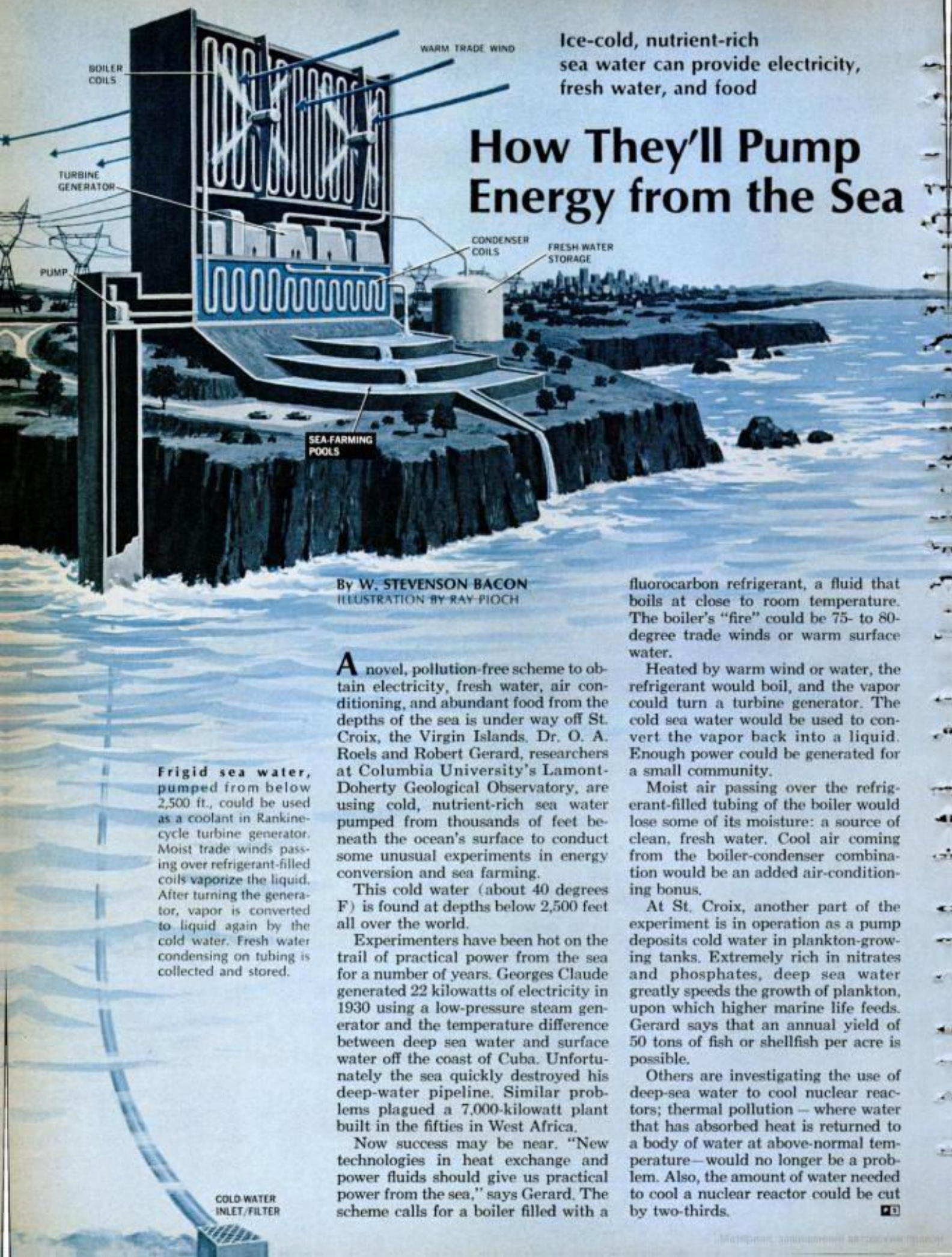
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Ice-cold, nutrient-rich sea water can provide electricity, fresh water, and food

How They'll Pump Energy from the Sea

By W. STEVENSON BACON
ILLUSTRATION BY RAY PLOCH

Frigid sea water, pumped from below 2,500 ft., could be used as a coolant in Rankine-cycle turbine generator. Moist trade winds passing over refrigerant-filled coils vaporize the liquid. After turning the generator, vapor is converted to liquid again by the cold water. Fresh water condensing on tubing is collected and stored.

A novel, pollution-free scheme to obtain electricity, fresh water, air conditioning, and abundant food from the depths of the sea is under way off St. Croix, the Virgin Islands. Dr. O. A. Roels and Robert Gerard, researchers at Columbia University's Lamont-Doherty Geological Observatory, are using cold, nutrient-rich sea water pumped from thousands of feet beneath the ocean's surface to conduct some unusual experiments in energy conversion and sea farming.

This cold water (about 40 degrees F) is found at depths below 2,500 feet all over the world.

Experimenters have been hot on the trail of practical power from the sea for a number of years. Georges Claude generated 22 kilowatts of electricity in 1930 using a low-pressure steam generator and the temperature difference between deep sea water and surface water off the coast of Cuba. Unfortunately the sea quickly destroyed his deep-water pipeline. Similar problems plagued a 7,000-kilowatt plant built in the fifties in West Africa.

Now success may be near. "New technologies in heat exchange and power fluids should give us practical power from the sea," says Gerard. The scheme calls for a boiler filled with a

fluorocarbon refrigerant, a fluid that boils at close to room temperature. The boiler's "fire" could be 75- to 80-degree trade winds or warm surface water.

Heated by warm wind or water, the refrigerant would boil, and the vapor could turn a turbine generator. The cold sea water would be used to convert the vapor back into a liquid. Enough power could be generated for a small community.

Moist air passing over the refrigerant-filled tubing of the boiler would lose some of its moisture: a source of clean, fresh water. Cool air coming from the boiler-condenser combination would be an added air-conditioning bonus.

At St. Croix, another part of the experiment is in operation as a pump deposits cold water in plankton-growing tanks. Extremely rich in nitrates and phosphates, deep sea water greatly speeds the growth of plankton, upon which higher marine life feeds. Gerard says that an annual yield of 50 tons of fish or shellfish per acre is possible.

Others are investigating the use of deep-sea water to cool nuclear reactors; thermal pollution—where water that has absorbed heat is returned to a body of water at above-normal temperature—would no longer be a problem. Also, the amount of water needed to cool a nuclear reactor could be cut by two-thirds.

SEPTEMBER 1971 60 CENTS

Popular Science

THE *What's New* MAGAZINE

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See-All-Around BUBBLE SUB

This unique research craft—the five-man Johnson-Sea-Link—will provide our first panoramic view of the deep oceans

By ARTHUR FISHER / Group Editor, Science and Engineering
PHOTOS BY OZZIE SWEET AND THE AUTHOR
ASSISTED BY BILL WAYMACK

GREAT HARBOR CAY, BAHAMAS

"Are you sure that's a sub?"

Our Bahamian boatman was doubtful, and I couldn't blame him. For the bizarre craft nestling on the stern of Sea Diver—the oceangoing research ship of famed inventor Edwin A. Link—looked more like a helicopter with its rotors clipped than a sub. Instead of a cigar-shaped hull, an open framework—festooned with spheres, tanks, bottles, and pods—glittered in the sun. Up front, highlights winked from what seemed to be a helicopter bubble.

We had set out from Great Harbor an hour before—with two photographers and about 400 pounds of camera equipment—in a Boston Whaler. We had chugged across deep blue water and through lime-green flats, where the bottom was just two feet down, to find the Sea Diver off the Stirrups, northernmost of the Berry Islands.

Now, as we drew closer, I could make out a white panel on the side of

the odd craft, with the words "Johnson-Sea-Link" and the sunburst emblem of the Smithsonian Institution emblazoned on it. It was indeed the sub we had come to see—a mobile habitat that will let scientists walk about on the seabed a thousand feet down.

The sub is named for its designer and donors, Link and J. Seward Johnson, of the pharmaceutical firm, Johnson & Johnson. The sub belongs to the Smithsonian, but is operated by Link's Sea Diver Corp. What makes the Sea-Link (I'll call it that for short) so special? In four days observing her sea trials, photographing her, talking to her crew and to official Navy visitors, and finally diving in her—I had ample time to learn.

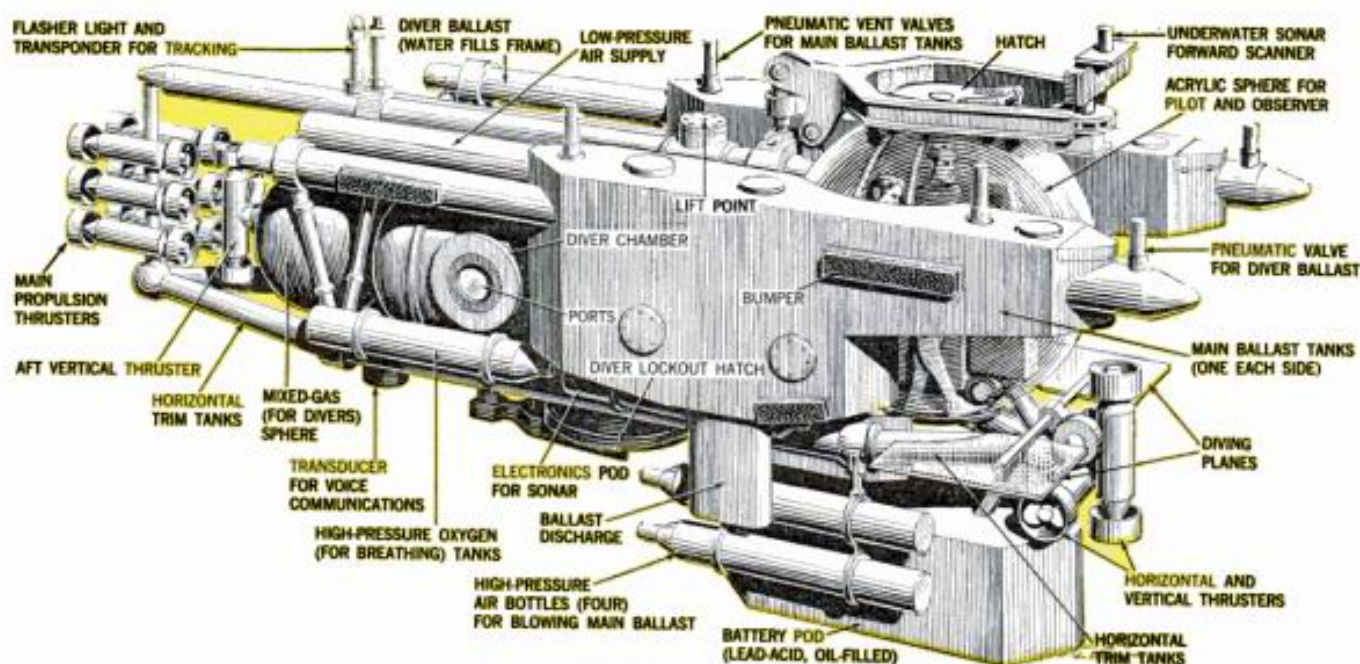
The Sea-Link is an inexpensive (\$450,000) 23-foot, 9½-ton, five-man submersible. It can carry two men in a 66-inch plastic sphere made of four-inch-thick acrylic, and three men in an eight-foot-long cylindrical welded-aluminum pressure hull that permits even inexperienced divers to "lock

out" and re-enter at depths of 1,000 feet or more, housing them for up to 48 hours. Both the diver chamber and the bubble are unique in the long and dangerous history of man underwater.

My first morning aboard the Sea Diver, we sat on deck after the Sea-Link had been secured from a dive with spry and limber Captain Link as pilot. With the roar of a compressor (charging air bottles) as accompaniment, Link filled me in on some background:

"The Sea-Link is much different from our previous sub, the Deep Diver" [PS, July '67]. "It's made from welded aluminum, not steel. Aluminum is corrosion-resistant, and the welding is able to withstand pressure much better than bolting. There are no chances of leaks or cracks that might let in salt water. The structure is lighter so we can carry a greater payload than with steel. And this ship has a modular construction with the pressure parts simply bolted to the frame. The whole ship can quickly be dismantled for servicing, or for airlifting someplace.

"Of course," Link continued, "the strikingly new element is the tremendous visibility with this acrylic sphere; it's vastly greater than we had with the little portholes on the Deep Diver." He waved at the plastic bubble now covered with a protective canvas shroud; two large silvery-gray air conditioning hoses snaked in through the open hatch. *Continued*





Diver scrambles aboard the Johnson-Sea-Link (above) before sub is picked up by mother ship, the Sea Diver. Unique underwater cyclorama is provided by a 66-inch-o.d. plastic bubble so strong it shelters two in a shirtsleeves environment even at depths of 2,000 feet. In submerged view (right), designer Link takes controls with Mrs. Link as observer. Size distortion results from photographing through water and four-inch-thick acrylic plastic. Observing from inside sphere is virtually distortion-free.

Modular construction of Johnson-Sea-Link appears in drawing at left. There are two manned pressure hulls: One, of transparent acrylic plastic, houses the pilot and an observer. The other, for three divers who can leave and re-enter through a hatch, is of welded aluminum, as is the rest of the sub. All components bolt into a rigid, tubular aluminum frame, parts of which fill with water and empty to adjust buoyancy and trim. Air bottles are for blowing ballast; oxygen tanks for breathing. A large sphere holds helium or mixed breathing gases for men in divers' hull. Twelve electric motors (1 puller, 1 pusher in each pod) provide propulsion; six others give vertical and lateral control.





With main ballast tanks blown, sub floats on surface with waterline about half-way up sphere, at top of diver chamber.



Water laps over the pilot sphere as the sub slowly dives. It gains negative buoyancy when pilot floods ballast tanks.



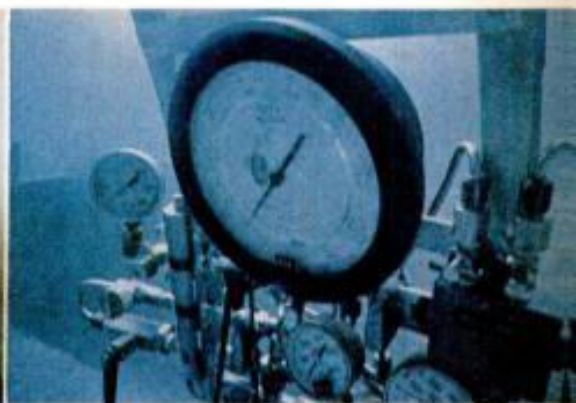
Fully submerged, sub prowls the bottom at search speed of half a knot. Electric motors give her complete mobility.



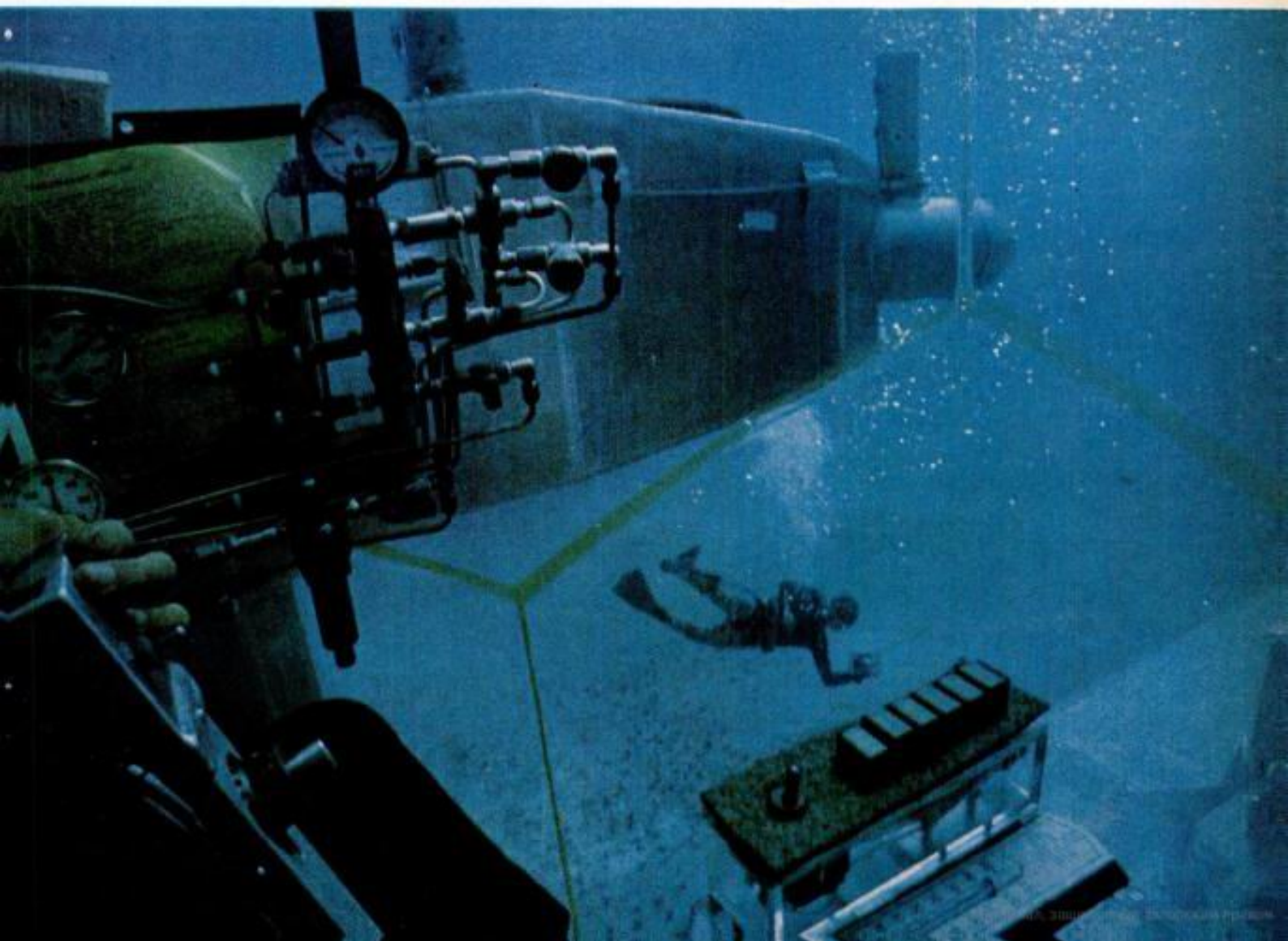
Clear of Sea Diver, we prepare to dive. Crewman in the water checks sub for gas leaks, potential sources of trouble.



Just under surface, with sunlight flooding sphere, depth gauge registers a few feet. Note bright red valve below it.

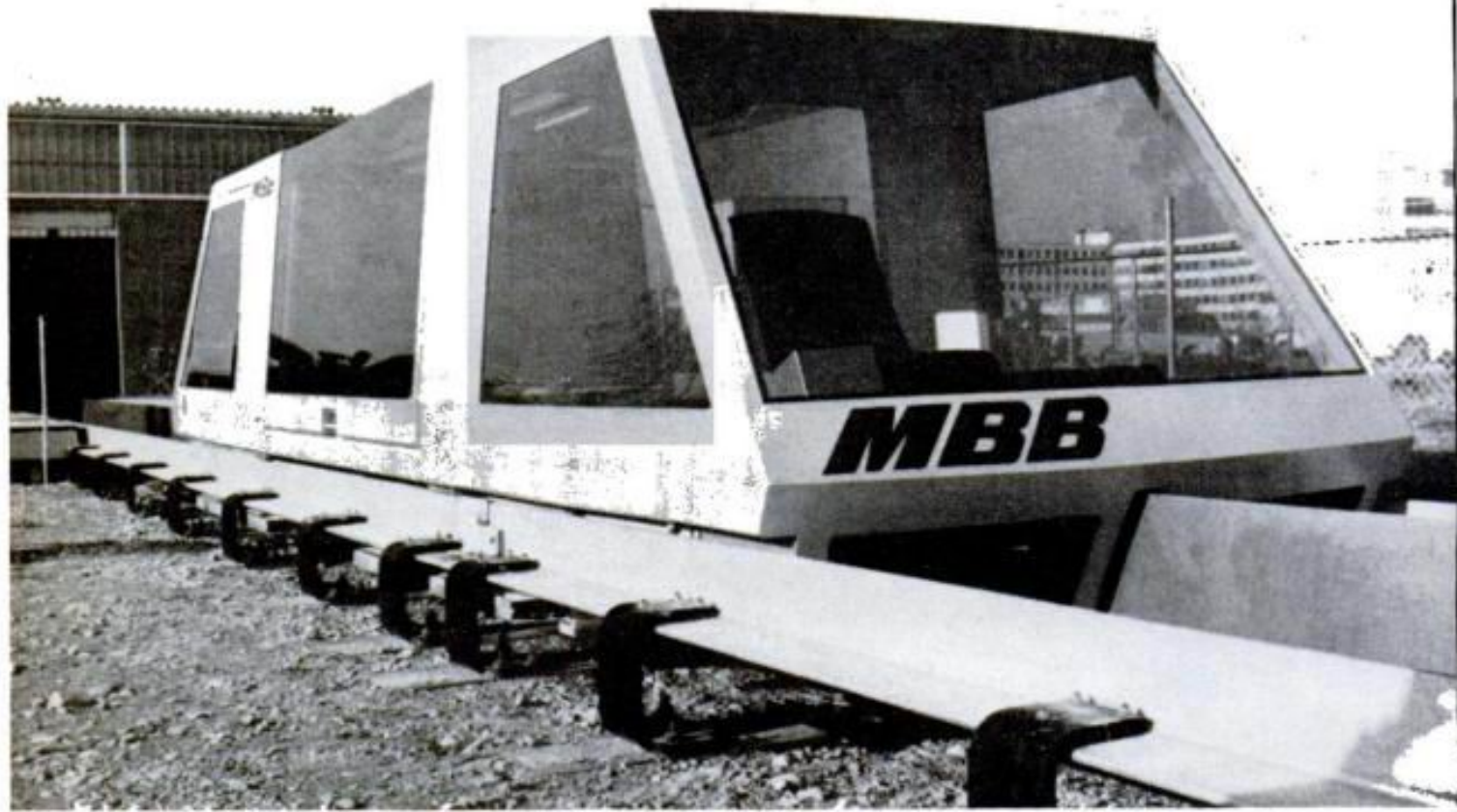


Inside of sphere is still bright, with depth gauge showing 34 feet, and visibility good, but red valve has lost color.



Is this experimental train the key to safe, silent, and economical high-speed transportation?

New No-Wheels Train Gets a



Five-ton car runs suspended by magnets from L-shaped rails elevated on U-shaped brackets. Powered by a linear-induction motor,

the train has done 40 mph on this experimental track. Unevenness of test track prevents running the vehicle at its top speed.

By DAVID SCOTT / *PS* European Editor

You sit back in a body-contoured seat and fasten the safety belt. You feel as though you're about to take a ride in a solarium, the view around you is so immense.

Ahead lies 720 yards of dead-straight track. Directly in front of you the driver pushes a button on a little control box. Electrical contactors click behind you, a subdued hum fills the cabin, and the platform alongside gently falls away about half an inch.

You're airborne in the German magnetic levitation train, a vehicle that could lead the way to the high-speed rail transport of the future. This future could come quickly, and 240 mph would be just the beginning.

The driver flicks a tiny joystick forward. More contactors close, and the thrust at your back is like that in a jetliner starting a takeoff run. In seconds, the scenery is whizzing

past. But there's no other trace of movement—no bounce, no jolts or vibration. And the only noise is a gentle medley of humming and rhythmic clicks as the collector shoes wipe along the power rails.

This new form of surface transportation could rival aircraft on real intercity run time; leapfrog tracked hovercraft on operating cost, performance, and comfort; and offer more safety than wheeled rail cars. Developed in Munich by Messerschmitt-Bölkow-Blohm, West Germany's largest aerospace group, the experimental five-ton railcar is suspended by electromagnets, and propelled by a linear induction motor.

No moving parts. In the entire vehicle there is nothing to wear or make noise. And there is no physical contact with the track other than the collector shoes. It's all done with magnetic fields.

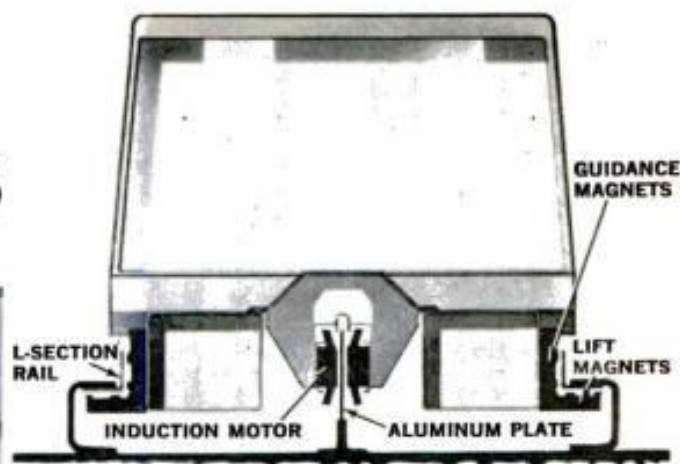
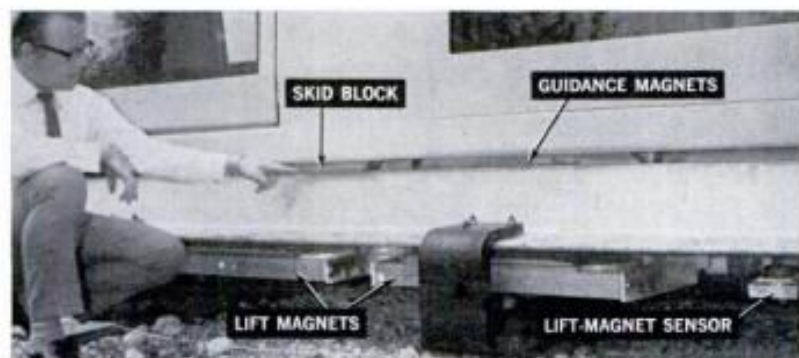
Now our driver flips the joystick to neutral. We're defying gravity in a frictionless coast. Only wind resis-

tance slows the car. While we're floating forward at a good clip, the driver pulls back the stick to reverse, and we lurch forward against the seat belt. The linear motor—trying to run backward—is dragging against the fixed reaction plate for powerful, silent braking.

Patented back in 1937, the idea of magnetic suspension is starting to move. Alert to the tremendous potential, MBB has in less than a year raced from the drawing board to a man-carrying test vehicle. The project was speeded by government money, and by drawing on top brains in missile and space technology.

The basic concept is ingenious. L-section steel rails raised a foot above sleepers on U-shaped brackets form the track. The car is actually suspended beneath the two rails by electromagnets on its frame. These face upward and pull against the flat track undersides, but don't touch them. When these magnets are de-energized, the car sets down against the tops of

Lift from Magnets



How it works: Above, lift magnets pull against L-section track to elevate car. Vertical-guidance magnets work against rail's vertical faces to keep car centered in tracks. Induction motor reacts against stationary aluminum plate to drive car and to apply braking force. At left: array of magnets and the sensors that control them.



Vertical aluminum plate is "rotor" of motor; the four dark rails carry 380-volt current.



Wide-angle view from cab of train is impressive. Driver has hand on joystick for

speed control and braking. Pushbuttons control lift and guidance magnets.

the rails on skid, or parking, blocks.

Lateral guidance is by a separate set of upright magnets facing and drawn to the vertical surfaces of the L section—again without contact.

Straddle-stance motor. Centered in the car frame is the linear motor with its flat parallel "stator" windings. Formed like an inverted U, it straddles the two-foot-high aluminum plate running down the center of the track. This stationary reaction element is the "rotor."

Since the stator windings are flat, instead of cylindrical as in a conventional motor, the magnetic field moves in a straight line rather than in a circle. It thus induces corresponding currents in the plate, imparting linear thrust to the coils.

Though designed merely to give the test car basic traction and not for brilliant acceleration or high speed, the present MBB motor still has a starting thrust of some 2,200 pounds, comparable to a small jet engine. The 174-kilowatt rating equals 240 hp,

and this is enough for a 60-mph capability even on the short test track, including stopping distance.

For braking at any speed you just switch over the input connections and the motor produces a reverse thrust equal to about half maximum forward thrust. That's another bonus to add to silent running and no wearing parts like bearings and brushes.

The 25-foot-long car is based on an alloy box-section frame for lightness. At each corner are one guidance and two lift magnets. Collector shoes pick up the 380-volt three-phase supply from four rails along the track. This AC current feeds the linear motor. For the magnets, it is stepped down and rectified to 60 volts DC, controlled by the voltage-regulating thyristors.

The crafty bit. The control system is what makes magnetic levitation shine. With the present setup, the normal air gap between individual lift magnets and the flat rail surface is about half an inch. But this can be

varied by a quarter inch in either direction to correct for unevenness in the rail. Correction is automatic and almost instantaneous, giving an absolutely smooth ride.

Here's how it's done: Just ahead of

[Continued on page 125]



Car can be moved with his fingertips while it floats in its tracks, author finds. Inside storage shed, DC power for magnets is fed through hefty cable.

New Champ in the Skyscraper League

Constructed in nine modular tubes, Chicago's 110-story Sears Tower will rise to 1,450 feet — to become the world's tallest building

By HERBERT SHULDINER

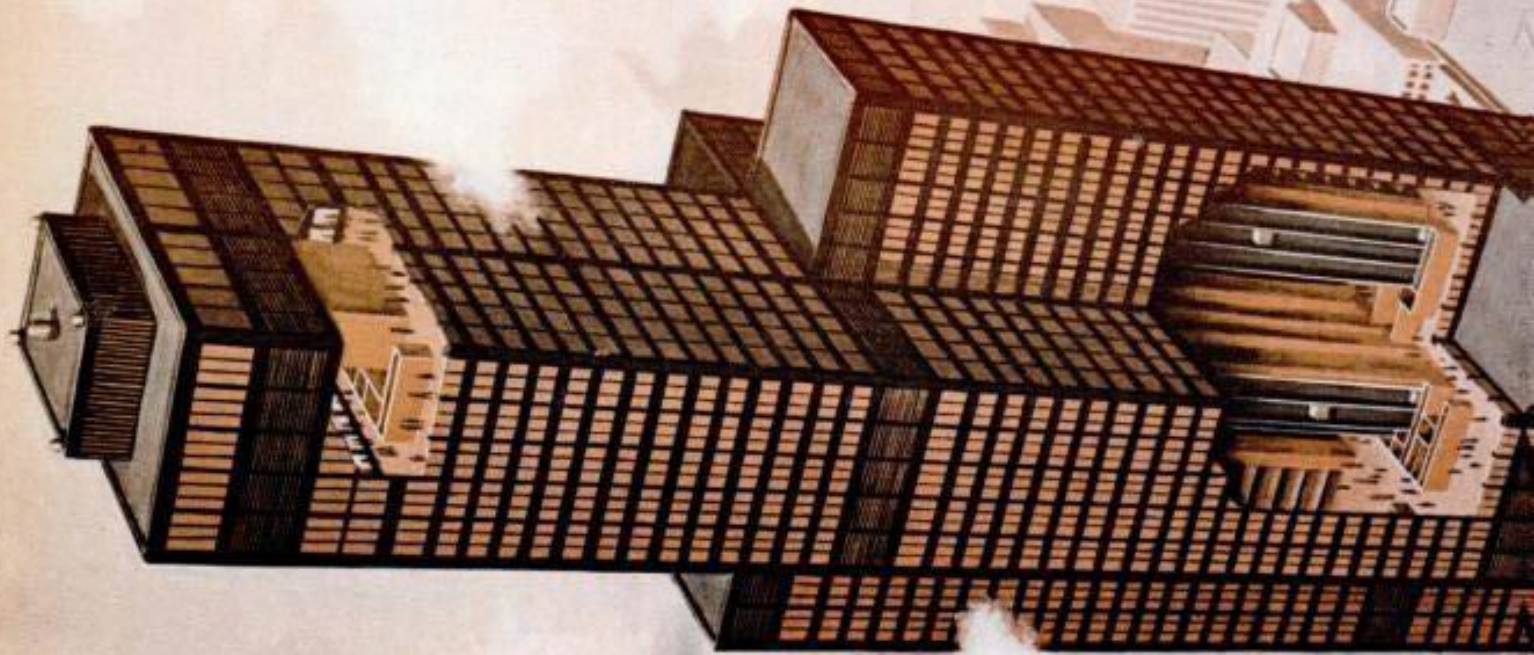
ILLUSTRATION BY RAY PIOCH

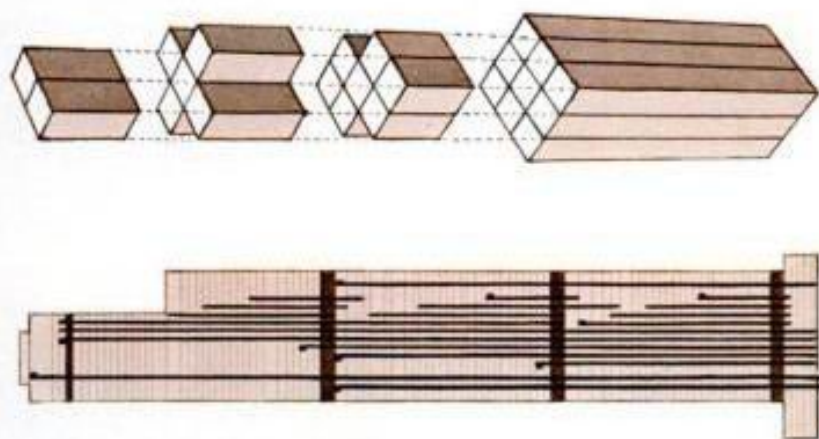
Soaring upward at the sizzling rate of two floors a week, the steel framework of Chicago's new Sears Tower is nearing the halfway point this month on its heady climb toward becoming the world's tallest building.

The new champ in the skyscraper league will top out late this fall at 110 stories — 1,450 feet high. It will, upon completion, eclipse the 100-story John Hancock Center (now Chicago's tallest building), the Empire State Building, and even the not-yet-completed World Trade Center in New York City [PS, May '71], whose twin 110-story towers presently hold world's-tallest-building honors. The Sears Tower will be 100 feet taller than the World Trade Center.

Of course, there are several giant TV antennas that are taller than the Sears Tower will be, but they're not buildings in the sense that people live or work in them.

In the heart of town. The Sears Tower is rising on a three-acre site in downtown Chicago. It occupies little more than an acre *Continued*





Huge Sears Tower will dominate Chicago's Loop when completed in 1974. It's built in the form of nine modular tubes (above right), which are stacked three square. Two modules drop off at 50th floor to form a Z shape. Two more drop off at the 66th floor to create a cruciform, remaining two modules soar upward from the 90th floor. The building will have 102 elevators divided into three zones as shown (above left), with express double-deckers serving the 33-34th, 66-67th, and 103rd story levels. Local cars will go to intermediate floors in the mammoth building.

Can We Harness Nuclear Fusion



By
EDWARD TELLER

Dr. Teller is University Professor of Physics at the University of California. He was an early authority in thermonuclear theory, and has made important contributions in many fields of physics. Dr. Teller maintains an active interest in nuclear-energy programs.

An eminent physicist tells where we stand in the search for clean, virtually unlimited power

In 1932, George Gamow, an ingenious Russian physicist who later moved to the United States, gave a lecture in Leningrad on the sun's source of energy. It couldn't be a simple chemical reaction such as burning—the available fuel would last for less than a million years. The energy of gravitational contraction would last not very much longer. Yet the sun was known to be billions of years old. The energy of the sun must come from nuclear fusion.

Nikolai Ivanovich Bukharin, one of the leaders of the Russian Revolution and early Communist government, was so impressed that he offered Gamow the entire power produced by the Leningrad electric grid for a few minutes each week to reproduce on earth what is happening on the sun.

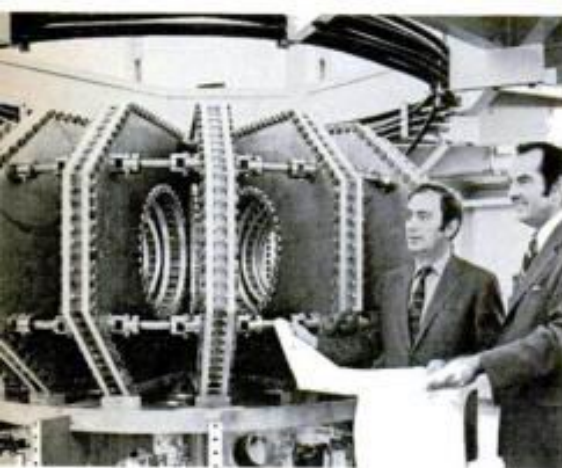
Gamow wisely declined. It was too early; neither he nor anyone else knew how to

The drawings and accompanying captions on pages 88 and 89 were prepared by the editors of Popular Science. More than 200 planned or operating fusion machines in 14 countries are now trying to achieve a sustained fusion reaction. As Dr. Teller explains in his article, the object is to heat a sufficiently dense plasma to a very high temperature and hold it there until nuclei fuse and release energy. On these pages are drawings of three machines that attempt to do just that in several different ways. None will actually produce a sustained reaction, but their designers hope they will lead to it.

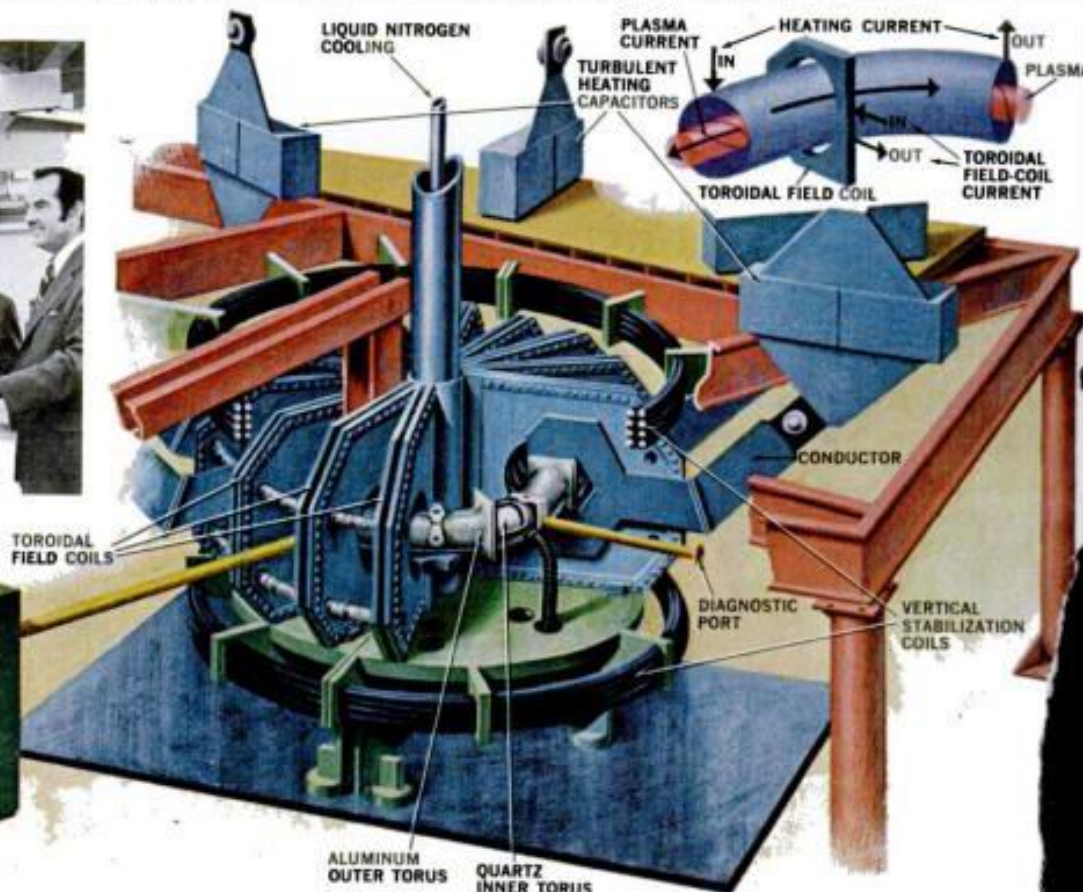
build a fusion reactor. We still don't know how for sure—but we are getting close to a long-sought goal: A self-sustaining thermonuclear reaction.

In principle, the problem is simple and is well understood. While many thermonuclear reactions produce energy in the sun, the main one is as follows: In the 30-million-

Continued



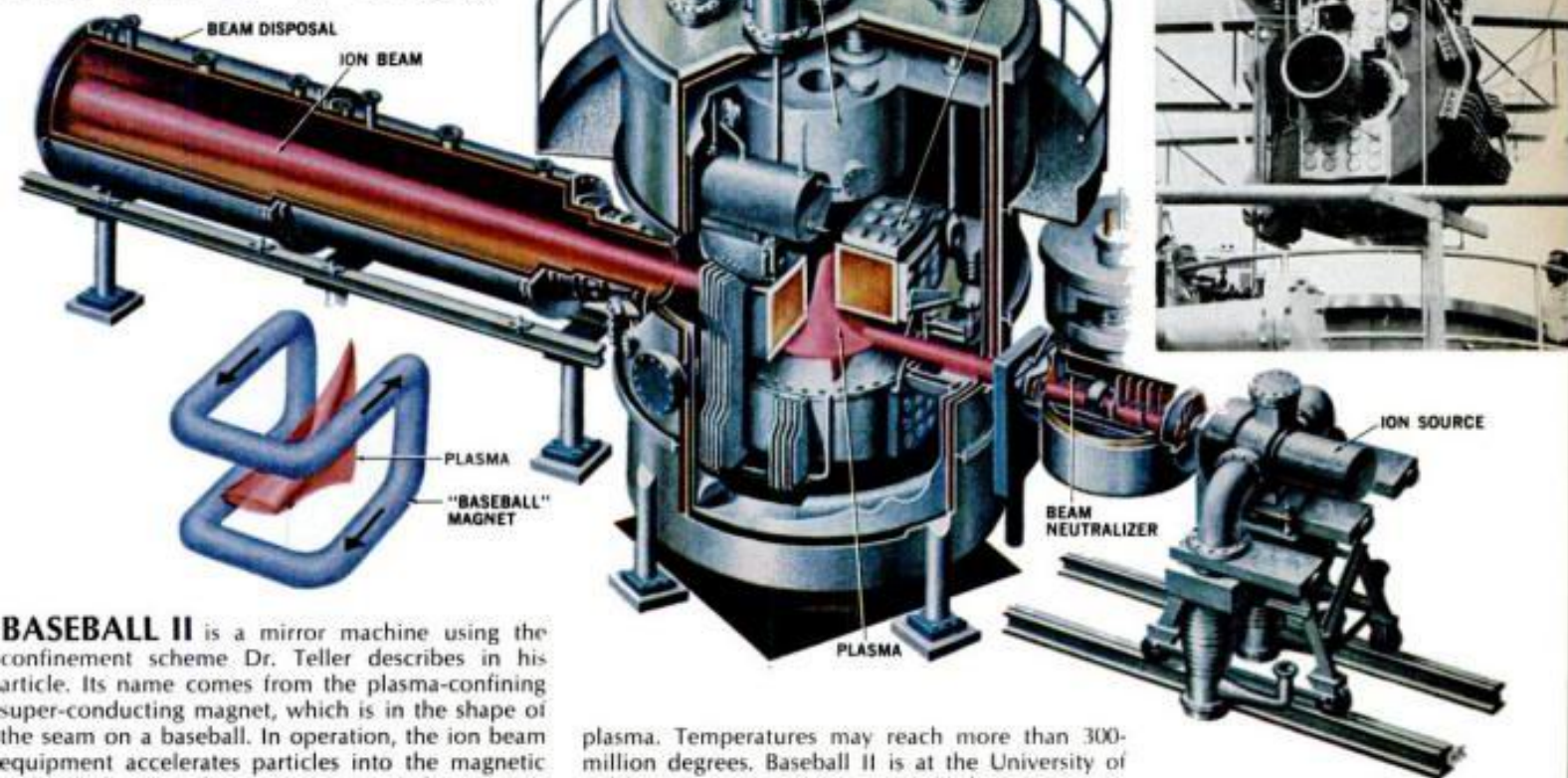
VACUUM PUMPS



IN A TOKAMAK, currents in field coils and in plasma itself produce a helical field to contain the plasma. In the University of Texas version shown, field coils can be seen; plasma current is induced when preheating capacitors (not shown) discharge

and set up a current flow along the length of the outer aluminum torus. A second bank of capacitors delivers a final jolt of current that provides turbulent heating to raise the temperature of the plasma to 100-million degrees.

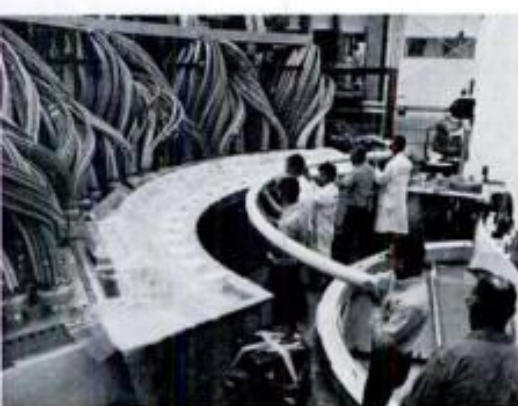
in the '70s?



BASEBALL II is a mirror machine using the confinement scheme Dr. Teller describes in his article. Its name comes from the plasma-confining super-conducting magnet, which is in the shape of the seam on a baseball. In operation, the ion beam equipment accelerates particles into the magnetic well so they can become a part of the reacting

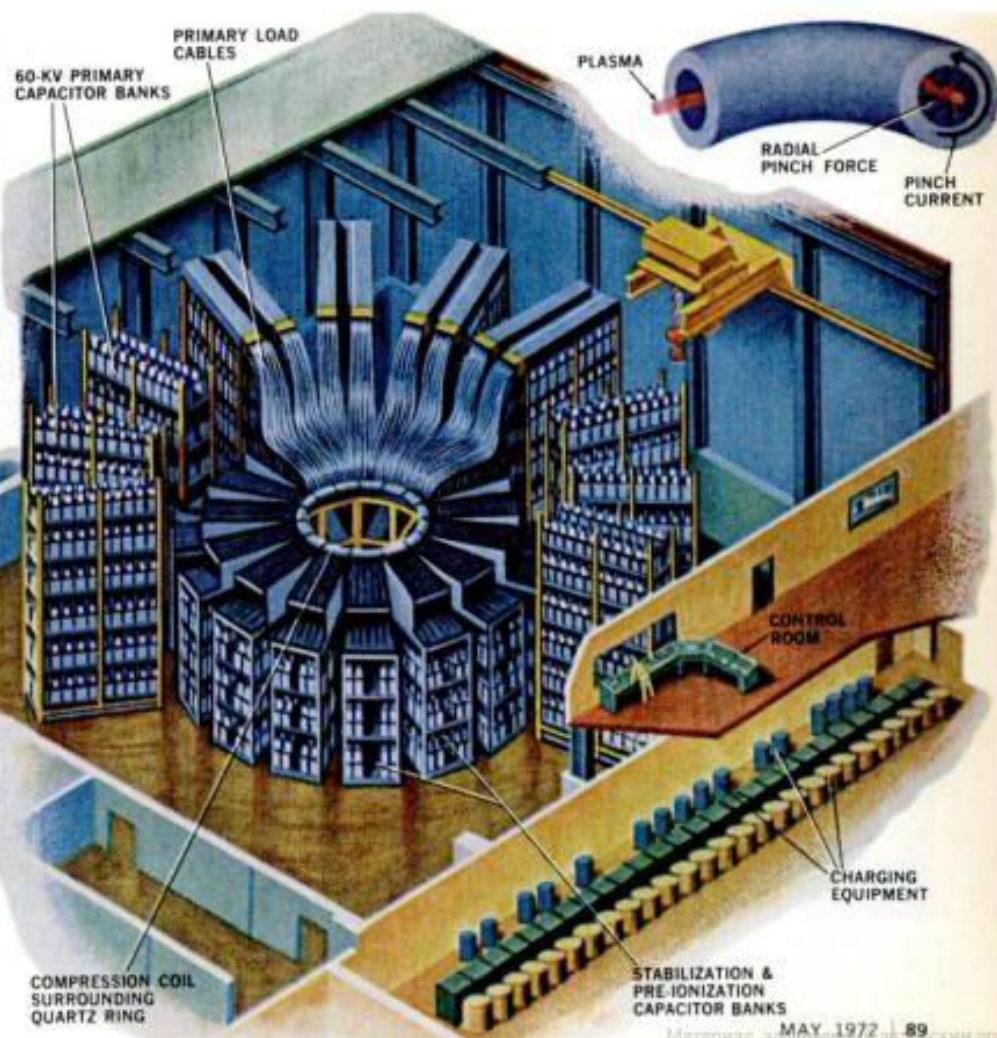
plasma. Temperatures may reach more than 300-million degrees. Baseball II is at the University of California's Lawrence Livermore Laboratory.

Illustrations By Howard Koslo



MAGNETIC PINCH. The huge Scyllac machine at Los Alamos Scientific Laboratory will use theta-pinch techniques to compress ionized gas into 50-million-degree plasma. Some 3,000 capacitors discharge into the aluminum compression coils surrounding the 16-foot-diameter quartz ring being assembled (bottom photo). The resultant pinch current (see diagram) generates a magnetic field parallel to the tube's axis. Bursts of current should constrict the gas into a high-density plasma, fusing nuclei.

CENTURY OF WONDERS: 1872-1972



MAY 1972 89



Aerial Transit System cars could speed overhead along cable-supported guideways at 120 mph; rush-hour auto traffic crawls at 10 mph.

The Transportation Muddle—

There Must Be a Better Way to Get From Here to There

By PAUL WAHL

In his 1972 State of the Union Message, President Nixon urged that top priority be given to the problem of mass transportation. It was not a very surprising recommendation. The American people have been stuck in too many traffic jams, squeezed into too many overloaded trains and buses, stacked up over too many airfields to need lecturing on the pitiful state of our transportation network.

The muddle has been with us for years, and seems to keep on getting worse. Why? Why is it so hard for us to get from here to there quickly, easily, and economically? And what

can we most efficiently do about it?

To get the answers for this special PS report on the transportation crisis, I canvassed dozens of experts—officials in the Department of Transportation and other government agencies, urban planners, engineers, transit administrators. What I uncovered was a complex mosaic of interlocking causes and effects—social and economic as well as technological. I found a record of past failures and neglects. But I also found a whole bevy of people-moving machines—air-cushion vehicles, magnetic-levitation trains, and others—that promise a fantastic new science of transportation for the future.

There is no single villain behind the muddle we're in. Of course, a

large part of the problem is that there are too many cars carrying too few people in and around cities. But much of this stems from the sheer lack of options for the driver—fast, comfortable, and reasonably priced public transport. Asking people commuting between Long Island and New York City, say, to choose between driving on the infamous L.I. Expressway ("world's longest parking lot") and traveling on the notorious L.I. Railroad, is inviting mass neurosis.

Cast in concrete? There exists a lively debate over the merits of the highway program, with some critics arguing that America is being "paved over." It seems more accurate to state, however, not that we spend too much

Continued



DHC-7 Quiet STOL turboprop airliner takes off from a future city STOLport. On short-

haul intercity flights it could cut today's jet-travel time in half, cost by a third.

money on highways, but rather too little on other modes of transport. Thus even automaker Henry Ford II, along with environmentalists, is urging that some of the Federal Highway Trust Fund money (from the four cents per gallon federal tax you pay on gasoline) be diverted to mass-transit development. The fund, which takes in five to six billion dollars a year, is used to build freeways. By contrast, the record budget of the federal Urban Mass Transportation Administration for 1973 is only one billion dollars.

The continuous deterioration of passenger service on our railroads has also contributed heavily to the abysmal state of transportation. We are now the only first-class nation in the

world that does not have first-class rail passenger service. Although we have 200,000 miles of railroad track threading the country, only one percent of intercity travel is by train.

Freight first. Recently, a friend took a train trip to Miami from New York City. He found it very pleasant, except for the frequent delays when freight trains competing for the same stretch of track were highballed through, while his train was repeatedly shunted to a siding. Reason: freight trains are now so long that they won't fit on the sidings; besides, freight is much more profitable to the rail lines—and therefore gets higher priority—than passengers.

Money, of course, has always been a determining factor in our transpor-

tation mess. As long ago as 1919, one-third of the urban transit companies were bankrupt, and President Wilson had to appoint a commission to study the situation.

What about all the shiny new gadgets we've been tantalized with—tracked air-cushion vehicles, linear-induction-motor-driven trains, STOL airbuses, magnetic-levitation craft, and the like? Aren't these devices the way out of our predicament? And if so, why aren't we putting this new technology to good use?

Will the show start? The answer is a complicated yes, no, and maybe. Yes there are fascinating new concepts in transportation hardware. But few are ready to be applied now—or very soon. And even if they were ready to go now, there would still be major questions—about money, social priorities, and even the plain orneriness of the average citizen when confronted with something new.

The Urban Mass Transportation Assistance Act of 1970 established a 12-year, \$10 billion program to expand and improve our common carriers. UMTA will use most of its billion-dollar 1973 budget—\$841.4 million—to help state and local transit authorities purchase badly needed equipment: 5,000 buses, 65 commuter rail cars, and 300 rapid-transit cars. For example, one of the commuter rail cars is the Garrett GT-4 dual-mode turboelectric, just ordered by the New York Metropolitan Transportation Authority. It can either be powered electrically from the existing third-rail system, or be self-powered by onboard gas turbines.

Of the \$115 million earmarked for R&D, \$66.4 million will be spent on new systems such as tracked air-cushion vehicles (TACV—pronounced "tack-vee") and personal rapid transit [PRT—see PS Nov. '71].

That may seem like lots of money. But note what the cost would be of a proposed TACV system providing a two-hour run on the 400 mile trip between Boston and Washington—\$2.7 billion.

A phone call brings the Dial-A-Ride Bus, radio-dispatched, in the Haddonfield, N.J. area. New service provides inexpensive door-to-door transportation—taxi convenience with bus economy.



Each pair seats 240 happy riders: Four Garrett dual-mode GT-4 turboelectric cars have just been ordered by NY's Metropolitan Transportation Authority for trial in commuter rail service.





Magnetic-levitation vehicles will compete strongly with STOL and TACV systems for short-haul intercity travel. Magnetic force between steel guide rails and onboard electromagnets gives lift, guidance to Krauss-Maffei Transrapid (scale model above), a 220-passenger vehicle that will reach speeds of more than 300 mph. KM's experimental MAGLEV vehicle (right) is now running on a test track near Munich.

Problems we don't need. Any high-speed ground transportation system takes an enormous investment, even if it's only modestly fast. The famed Japanese Bullet Train between Tokyo and Osaka (about 400 miles), required a new roadbed, although its top speed is only 125 mph. Cost in 1964: \$1.1 billion. And wear and tear on the track is so great that there are constant maintenance problems.

Some proposed new systems require tunneling. A study by TRW for the DoT showed it would cost \$176.5 million to develop a 450-mph underground system, but another \$4.6 billion to build a two-way tunnel!

And even when the money becomes available, planners must gamble on public acceptance of a given system. In Pittsburgh, the UMTA-backed Skybus, an automated rapid-transit vehicle to ride on rubber tires over dual-rail elevated concrete tracks, is meeting local opposition.

Really high-speed ground systems—above 200 mph—demand unconven-



tional suspension and contact systems; wheels on tracks just don't work well at these speeds. Two kinds of noncontact systems—the tracked air-cushion vehicle and the magnetic-levitation vehicle, as well as various hybrid systems—are under vigorous development. Both are capable of speeds over 300 mph.

Our Department of Transportation is betting heavily on the TACV. Under contract with the Federal Railroad Administration, Grumman Aero-

space Corp. is completing a 300-mph tracked air-cushion research vehicle (TACRV), which will glide about the DoT High Speed Ground Test Center in Pueblo, Colo., held off the ground by a thin layer of air.

This February, UMTA awarded a \$5 million contract to Rohr Industries to build an operating prototype Urban TACV designed to carry 60 passengers at speeds of 170 mph, a project scheduled for completion in 1973.

[Continued on page 182]



LIM-powered, the 60-passenger Urban TACV will cruise at 150 mph, suspended above its guideway on a very thin cushion of air.

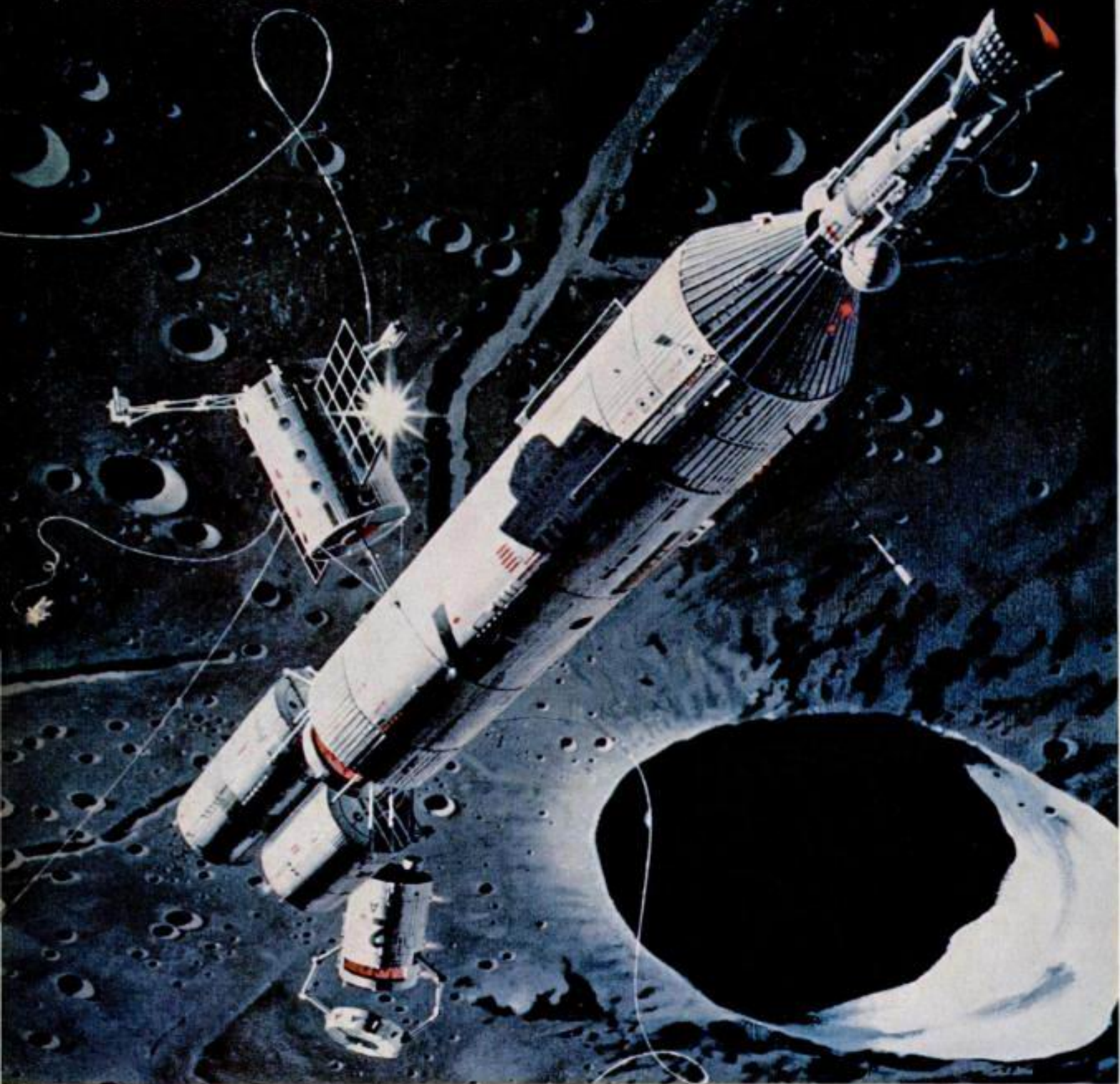


Automated Airtrans electric vehicles like this will move people at the new Dallas-Ft. Worth Regional Airport, opening in 1973.



Test bed for future high-speed ground transport systems is Grumman's 300-mph tracked air-cushion research vehicle.

Mooncraft of the Future



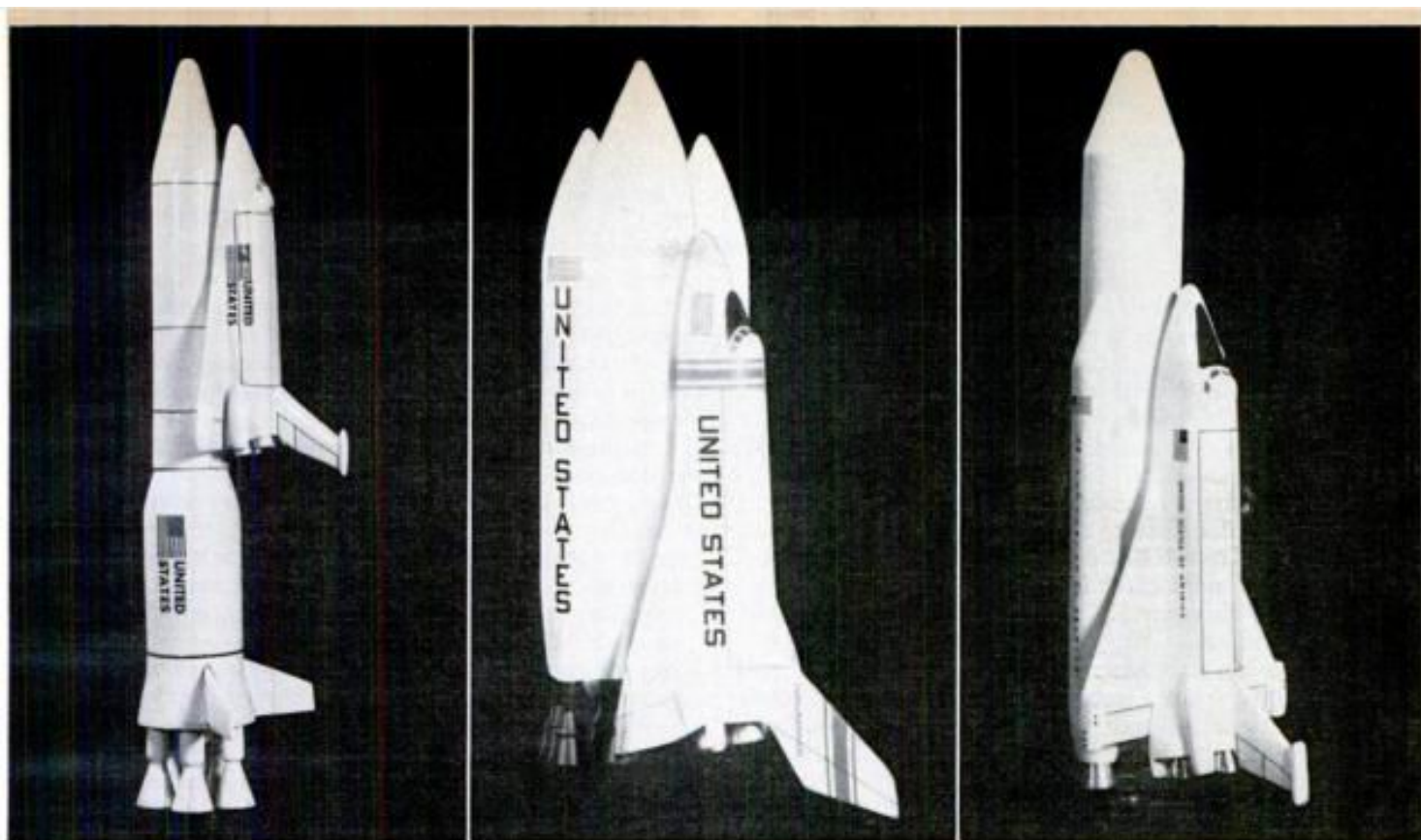
What will our ventures in space be like in the distant future? To give PS readers a glimpse of one possibility, we chose this painting from famed artist Bob McCall's one-man show on space themes at the Smithsonian Institution. It shows a nuclear space shuttle designed to travel between Earth and lunar orbit. The manned, cargo-carrying ship (its crew

compartment in red) is being off-loaded by a lunar space tug, which has already taken a wafer-shaped cargo pod off a stack. The tug places the pods on its "head" and descends to base.

In front of the shuttle, sunlight glinting off its solar panels, a small space station is in synchronous orbit about the moon. Its crew of six to ten

men monitor the cargo transfer, alert for trouble.

Will a scene like this ever unfold on the moon—and if so, when? We don't know the answers. But recently our country took the next positive step into space by deciding to build a space shuttle. For the full story, read the article by Dr. von Braun starting on the opposite page.—Arthur Fisher



After accelerating orbiter and its huge fuel tank to Mach 4, six-engine booster in this McDonnell Douglas design drops away.

In a Grumman design, two pressure-fed, liquid-fuel boosters are mounted on orbiter's fuel tank, which is ejected once in orbit.

Solid-fuel boosters would be jettisoned 35 miles up after burning in parallel with orbiter engine. North American Rockwell design.



SPACE SHUTTLES GET THE GREEN LIGHT

By **WERNHER von BRAUN**

NASA Deputy Associate Administrator
PS Consulting Editor on Space

NASA is now moving quickly to develop a reusable space transportation system. Here's how we'll put it to use after Apollo

At a special Kennedy Space Center launch complex sometime in the late seventies, massive high-bay hangar doors will slide open. Slowly, ponderously, an odd-shaped space vehicle will emerge on a treaded crawler transport and inch toward a nearby launch pad.

The vehicle, the nation's first reusable space transportation system, is moving rapidly into the development stage following President Nixon's January endorsement of the space-shuttle concept. The President said, "The space shuttle will give us routine access to space by sharply reducing costs in dollars and preparation time."

This multipurpose shuttle, which will take off like a rocket, fly in orbit like a spaceship, and land like an airplane, will replace almost all present expendable launch vehicles. It will carry into space most of the nation's payloads, scientific and applications, manned and unmanned, civilian and military.

Towering as high as 175 feet—about 17 stories—the

space shuttle will weigh some 4.7 million pounds when fueled for launch. It will have a delta-wing, airplane-like orbiter about the size of a DC-9 sidestrapped to its disposable liquid-hydrogen/liquid-oxygen tank.

It will also have a booster, and depending on the booster configuration selected this spring, the launch sequence will vary slightly. Using one competing design as an example (left photo above), here is how a shuttle mission would develop.

In this version, an unmanned, liquid-fuel booster is attached to the tail end of a large propellant tank to which the delta-wing orbiter is piggybacked. The booster's propellants—kerosene and liquid oxygen—would be fed into six one-million-pound-thrust rocket engines by about 300 pounds of pressure in the tanks.

A crew of two will pilot the orbiter, which may also carry two flight engineers to check out unmanned satellite payloads and deploy them in space. The orbiter is powered by three 470,000-pound-thrust high-pressure engines, fed from the large liquid-hydrogen/liquid-oxygen tank to which the orbiter is side-strapped. Carrying these propellants outside the orbiter provides space for a roomy cargo bay: 15 feet in diameter and 60 feet long—big enough to accommodate a Greyhound bus. Payloads up to 65,000 pounds will be possible.

Manned-booster concept abandoned. After blast-off, at an altitude of 35 to 40 miles and moving at about Mach 4, the booster is jettisoned. It follows a ballistic flight path and, supported by a cluster of parachutes, splashes into

Continued

"The space shuttle will give us routine access to space . . ."

the ocean 200 to 300 miles downrange. Earlier concepts envisioned a manned 747-size booster, to which a manned 707-size orbiter would be side-strapped. But the fly-back booster concept [PS, July '70], with its prohibitive development price tag, has now been abandoned in favor of the unmanned ballistic booster that can be recovered, refurbished, and reused.

The orbiter, using its three engines, will achieve orbit with its huge propellant tank still strapped beneath its belly. Here the tank will be detached. It can be pushed back into the atmosphere with a small rocket; reentry can be timed so that debris surviving the fiery trip falls into remote ocean areas.

Instead of a single booster pushing against the orbiter's external propellant tank, study contractors have also looked into the feasibility of two parallel-mounted, pressure-fed liquid boosters (middle photo, preceding page). Even solid-fuel boosters, expendable as well as reusable, have been studied (right photo).

Depending on mission requirements, the orbiter will remain in orbit from a week to 30 days. Then the crew will pilot the orbiter back to Earth for an airplane-type landing on a runway constructed near the launch complex. Enough fuel for orbital maneuvers and reentry is carried in the fuselage. From its reentry point, the orbiter will

have a cross-range maneuvering capability of 1,100 miles.

Even if we allow \$2 million for each orbiter fuel tank lost on a mission, total flight cost, with reusable liquid-fuel boosters, is estimated at \$7.7 million. With solid-fuel boosters, it may run \$10 million per flight, but development cost would be lower. Even \$10 million is far less than the cost of today's expendable launch vehicles (except the little Scout), and yet the shuttle's orbital payload capability of 65,000 pounds exceeds all except the giant Saturn 5. An estimated \$5.5 billion over a six-year period will be needed to develop the shuttle system.

Manned or unmanned space flight? Saving in transportation cost, however, is only one of the shuttle's promised blessings. Unmanned satellites can be repaired or serviced by men in space, or returned to Earth for refurbishment, updating, and reuse. Shuttles will greatly reduce satellite mortalities: A high percentage of automated satellites fail immediately after injection into orbit. Antennas fail to unfurl, sensor systems may not respond to ground command, or batteries may run down in a few hours when solar-cell arrays deploy improperly.

With the shuttle, user agencies may seriously consider buying a satellite "FOB orbit." The supplier would send an activation crew along when the shuttle carries the satellite into orbit (see drawing, left).

The old argument over manned vs. unmanned space flight should thus simply disappear. With manned, reusable shuttles providing cheaper transportation into orbit than any other system, the shuttle will corner the space-transportation market.

But man's future role in space will far exceed his contributions in service and maintenance. The shuttle's huge cargo compartment can accommodate Research and Applications Modules (RAMs)—house-trailer-size, pressurized cylinders developed for research and exploratory missions.

Trimming costs with standard equipment. RAMs will become a modular home for a variety of space laboratories. (No one has yet suggested running an entire research laboratory by computer!) The shuttle's ample payload capability will free researchers from weight constraints, while the benign shuttle environment—low acceleration, low vibrations, no temperature extremes—along with man's presence in the RAM, will permit extended use of standard laboratory equipment.

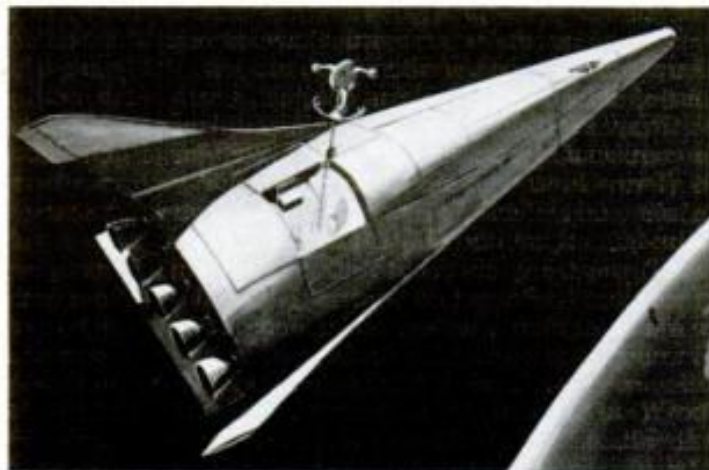
Today, a sophisticated, automated spacecraft costs up to \$30,000 per pound. Standard laboratory equipment placed in a RAM will cost an average of as little as \$100 per pound; specially constructed, highly miniaturized equipment so expensive to develop won't be necessary.

Missions of this kind may be flown in the "sortie mode": Several non-astronaut scientists would participate in a 10-day flight. During this time they would finish their carefully prepared measuring program involving astronomy, meteorology, oceanography, Earth resources, medical studies, zero-gravity processing techniques, or just basic physics and chemistry.

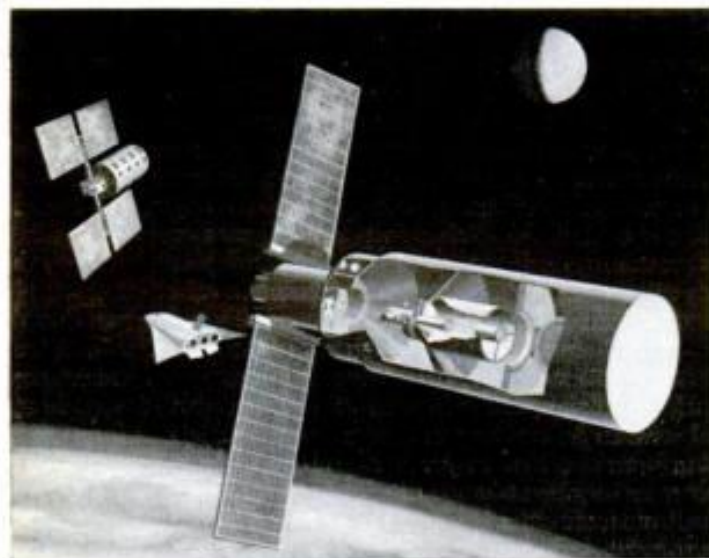
After obtaining their data, the scientists would return to Earth with the equipment, analyze the data, and write their papers. The RAM would then be refitted for the next sortie mission. For astronomical missions, where precise telescope alignment is essential, the RAM may even be disconnected from the orbiter to float freely nearby (see bottom drawing at left).

Test flights should begin in 1976, manned orbital test flights in 1978, and an operational shuttle should be ready before 1980.

[Note: At press time, NASA announced it has decided to use solid-fuel rockets to launch space shuttles.]



Activation crew for satellites would deploy antennas and solar panels. Before releasing satellite from extension arm to shuttle, they would confirm good data reception at ground stations.



Astronomical modules illustrated could be placed in orbit by separate shuttle orbiters. Programmed to operate automatically for weeks, they would be visited periodically for film removal.

The Atomic Plant with a Foghorn

A generating station at sea may set the style for our big electric-power "nukes" of the next decade

ILLUSTRATION BY RAY PIOCH

Three-quarters of a billion dollars says a power station in the ocean is no pipe dream. That's the amount of a contract just signed for the world's first offshore nuclear-power plant—the 2,300,000-kilowatt Atlantic Generating Station of New Jersey's Public Service Electric and Gas Company.

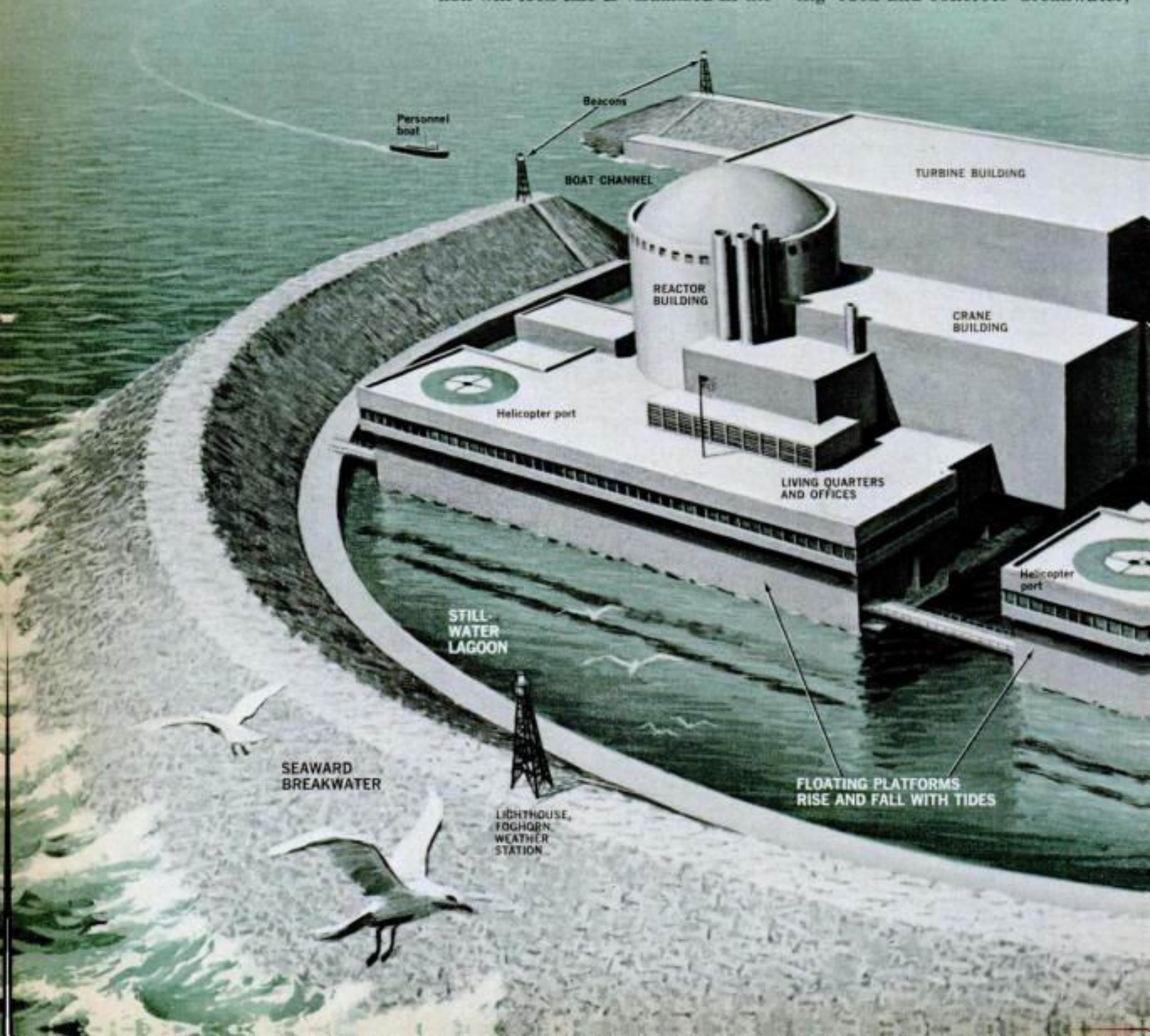
Its Atlantic Ocean site will be in water about 40 feet deep, 2.8 miles off Little Egg Harbor inlet, N.J., and about 12 miles northeast of Atlantic City. Steam-heated cooling water from its turbines' thirsty condensers will be discharged innocuously into the vast sea all around. This unique capability makes it the pioneering example of an alternative to building more A-plants on inland rivers, at risk of overheating the streams to the point of thermal pollution harmful to aquatic life.

What the Atlantic Generating Station will look like is visualized in the

drawing below. A striking novelty will be the unconventional features imposed by its marine setting—service boats, beacons, even a foghorn.

Offshore station's design. Twin floating platforms will measure about 380 by 400 feet apiece, a total area large enough for four football fields. Each platform will support a 1,150,000-kw atomic-power reactor—larger than any operating in the U.S. today—of the time-tested pressurized-water type, together with associated electric generating equipment. The uranium-fueled reactor's heat will make steam to run turbines and drive a mighty generator. Buried in the sea floor, 345,000-volt electric cables will carry the torrent of power ashore.

For protection from waves and any blundering vessel, the moored platforms will be surrounded by a towering rock-and-concrete breakwater,



resting on sea bottom, that Public Service calls "the largest and strongest structure ever built in the ocean." Two openings admit boats carrying men and supplies, and let in sea water for the turbines' condensers—which return it, warmed, to the ocean via a submerged duct through the breakwater's shoreward side.

Workers will reach the ocean site by boat from a shore supporting facility with a parking lot and dock. Helicopter ports on the station will serve visitors arriving by air.

Crews live aboard. Operating crews will live at sea for several days at a time, alternating with several days off ashore. Each floating unit's living facilities include a cafeteria seating 100, a recreation room and library, and sleeping quarters. Fresh water for drinking—and for steam-making—comes from a sea-water distilling sys-

tem, as on ships. Telephone and radio link the plant to shore.

Population of the "atomic island" will vary from close to 24—the total operating personnel—up to some 200 when maintenance men periodically swell the figure. Each of the twin generating units can be operated by a crew of six and will always have two crews aboard, one working while the other rests.

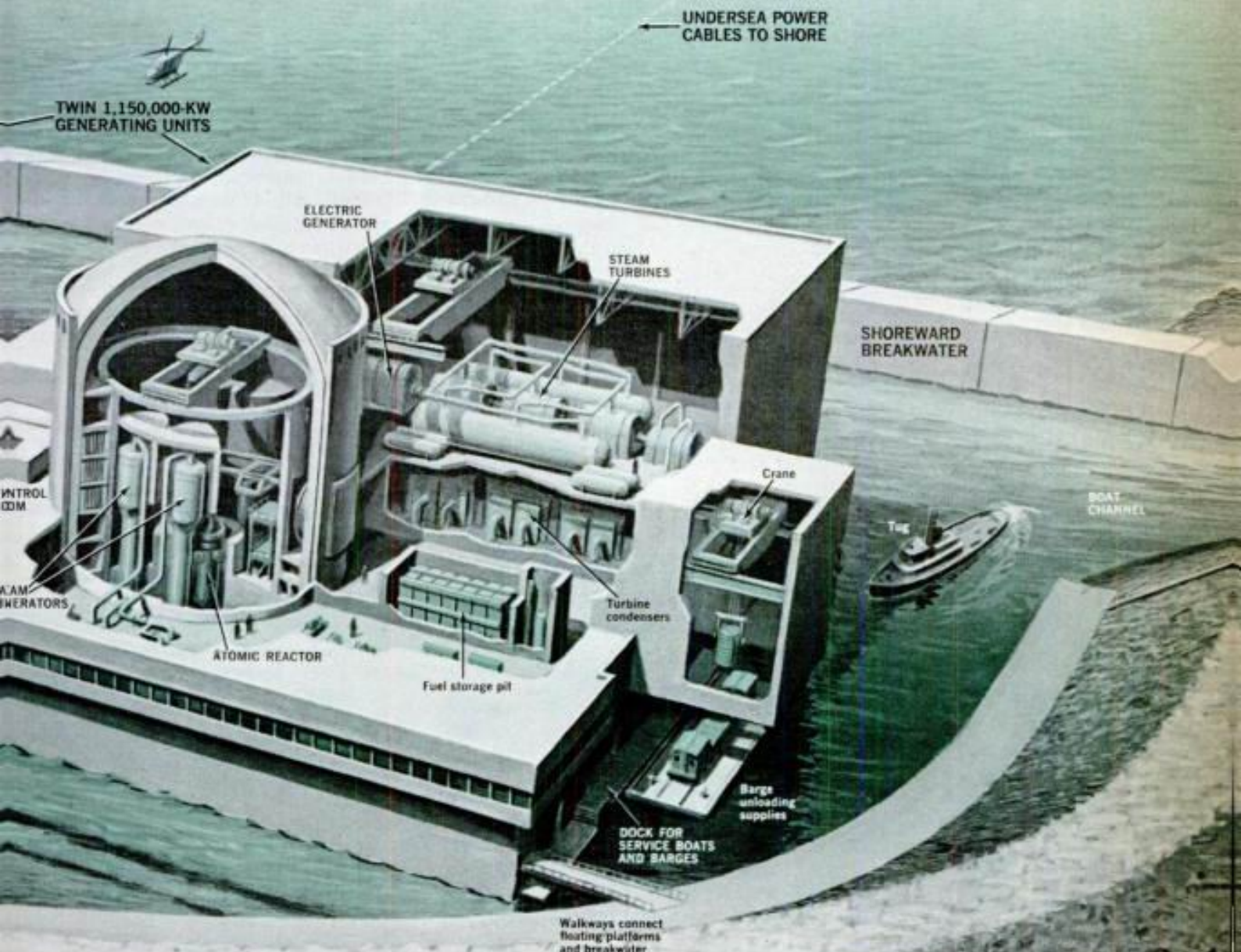
Planners say the atomic plant will leave a seashore view unspoiled. Seen from land—which will take a clear day—it will be no more conspicuous than a distant ship, for which it could be mistaken.

"Assembly-line" building plans. Ocean atomic-power stations off U.S. coasts are seen as the coming thing by Offshore Power Systems, a joint venture of Westinghouse Electric Corp. and Tenneco, Inc. A waterfront fac-

tory it's building at Jacksonville, Fla., will construct up to four a year in assembly-line fashion. On completion they'll be towed by sea to locations.

Offshore Power's first order is Public Service's \$750,000,000 one for two of the units—the biggest equipment buy in electric-utility history. The breakwater, which Public Service will build itself, will bring its Atlantic Generating Station's cost to an even billion.

Environmental studies by Public Service, already well under way, will support it in applying for some 50 needed permits from local, state, and federal agencies. Actual construction of its floating power units is expected to begin at Jacksonville in 1975, and of the breakwater at the site in 1976. The schedule calls for one generating unit to be in operation by 1980 and both by 1981.—Alden P. Armagnac



Ray Focht

Riding the Shuttle to the Bottom of the Sea

An elevator to the bottom of the sea? Our reporter takes a ride in one — first of its kind — to see how oilmen may soon be hooking up to deep, sea-floor wells.

By **ROBERT GANNON**

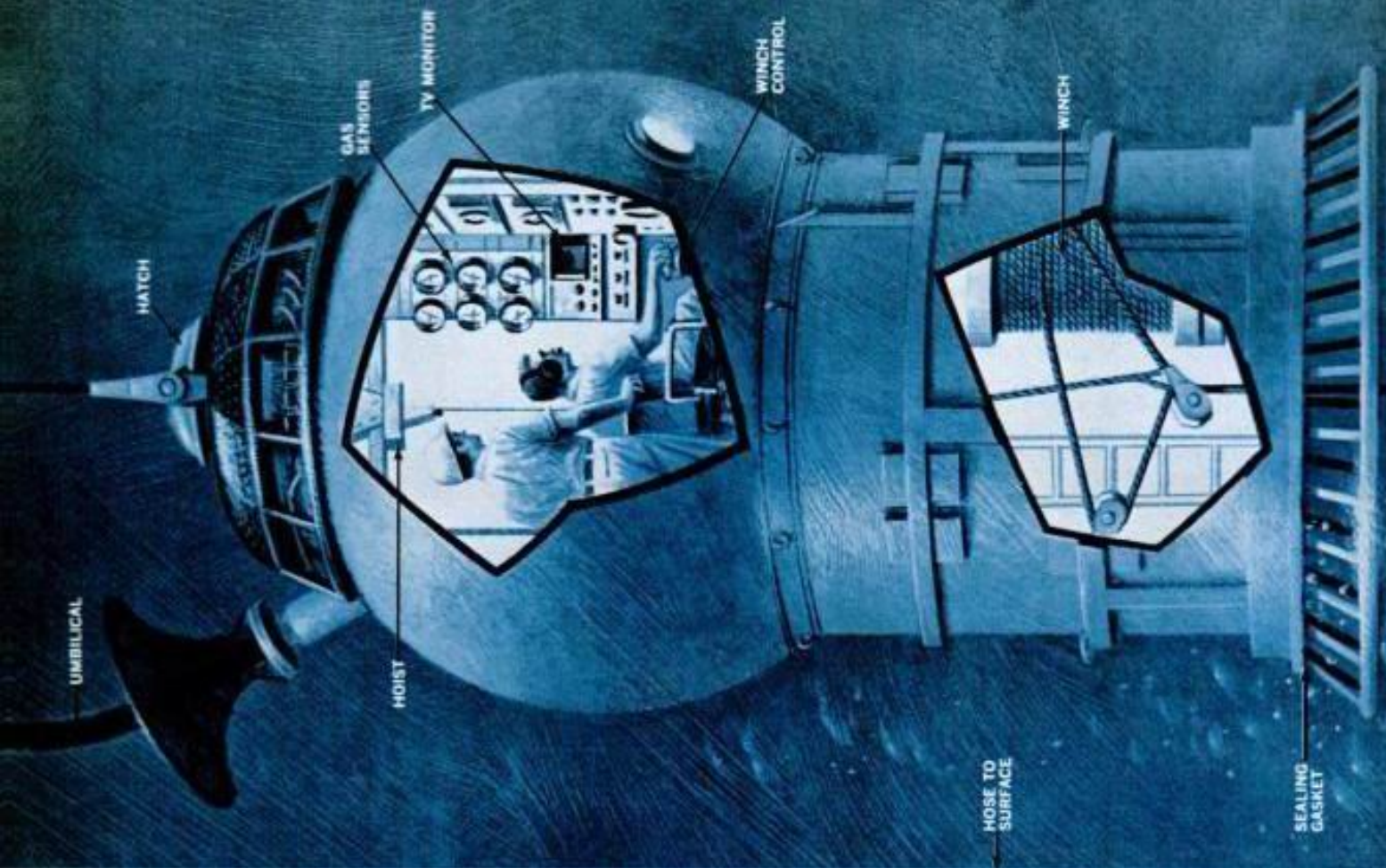
DRAWING BY HOWARD KOSLOW



It was the size of a Volkswagen bus, was crammed with instruments, tools, gauges, and levers — and smelled of wet steel. Down between the captain's feet nestled a five-inch port; above his head a television camera watched; and off to his right, for some reason nobody could explain, a wallet-size picture of the Mona Lisa peered at all of us.

I sat on a coil of cables, trying to keep out of the way, and down below me, curled up in the lower hatch, the other member of the crew, Ron Bell, stared down through the bottom port. The temperature was edging to 90 degrees, and whenever I moved suddenly, drops of sweat fell down on him. He didn't mind — he was used to it, he said.

We were in a diving bell, a first-of-its-kind submersible that promises to work a major change in the offshore oil industry. We were 100 miles southeast of New Orleans,



heading down toward the undersea snout of an oil well more than 300 feet below.

Three days earlier, the well — drilled months before — had been hooked to oil lines, and soon would be producing oil. This was the deepest underwater well ever completed — and what made it possible was this submersible capsule.

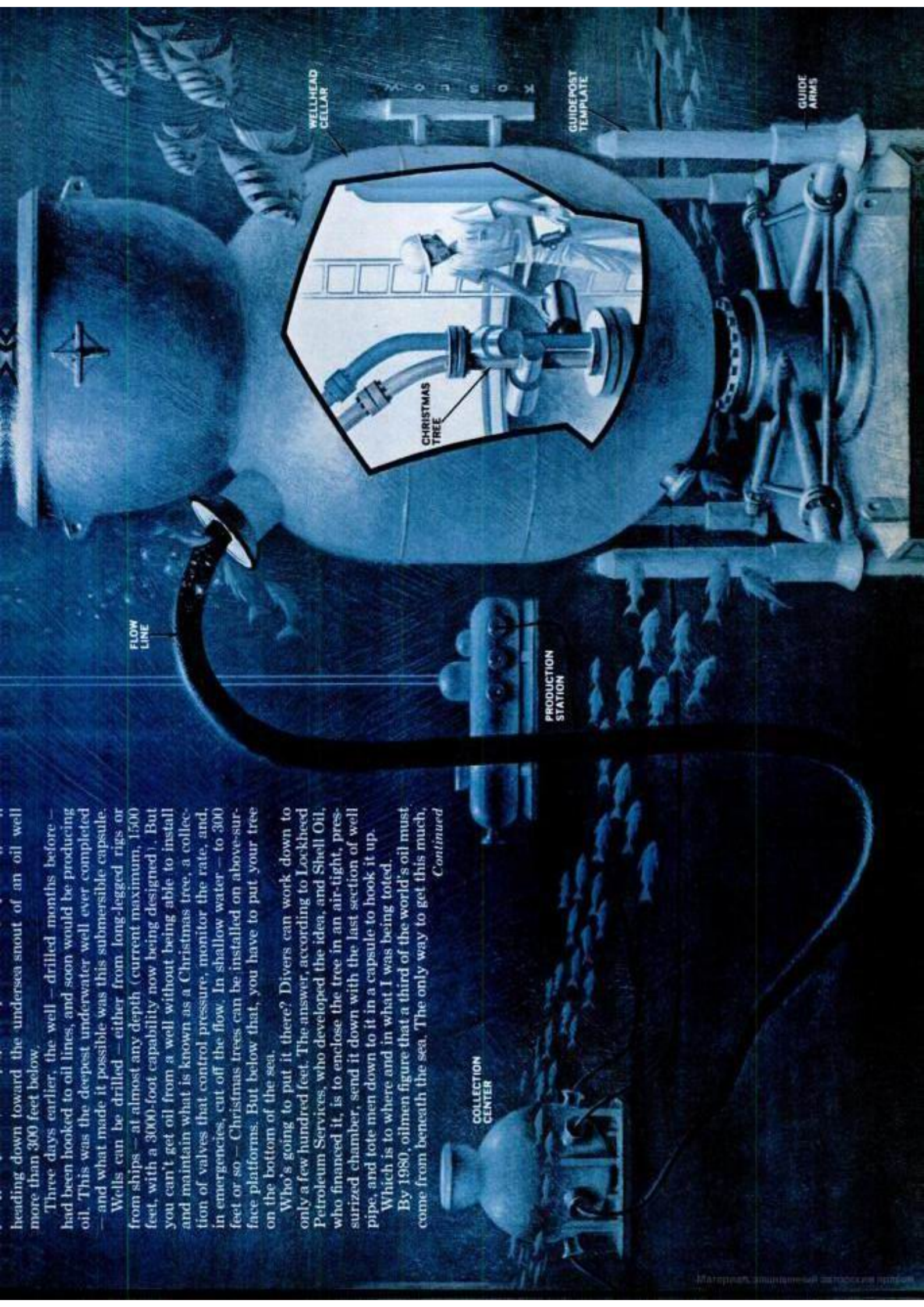
Wells can be drilled — either from long-legged rigs or from ships — at almost any depth (current maximum, 1500 feet, with a 3000-foot capability now being designed). But you can't get oil from a well without being able to install and maintain what is known as a Christmas tree, a collection of valves that control pressure, monitor the rate, and, in emergencies, cut off the flow. In shallow water — to 300 feet or so — Christmas trees can be installed on above-surface platforms. But below that, you have to put your tree on the bottom of the sea.

Who's going to put it there? Divers can work down to only a few hundred feet. The answer, according to Lockheed Petroleum Services, who developed the idea, and Shell Oil, who financed it, is to enclose the tree in an air-tight, pressurized chamber, send it down with the last section of well pipe, and tote men down to it in a capsule to hook it up.

Which is to where and in what I was being toled.

By 1980, oilmen figure that a third of the world's oil must come from beneath the sea. The only way to get this much,

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250-PASSENGER HYDROFOIL

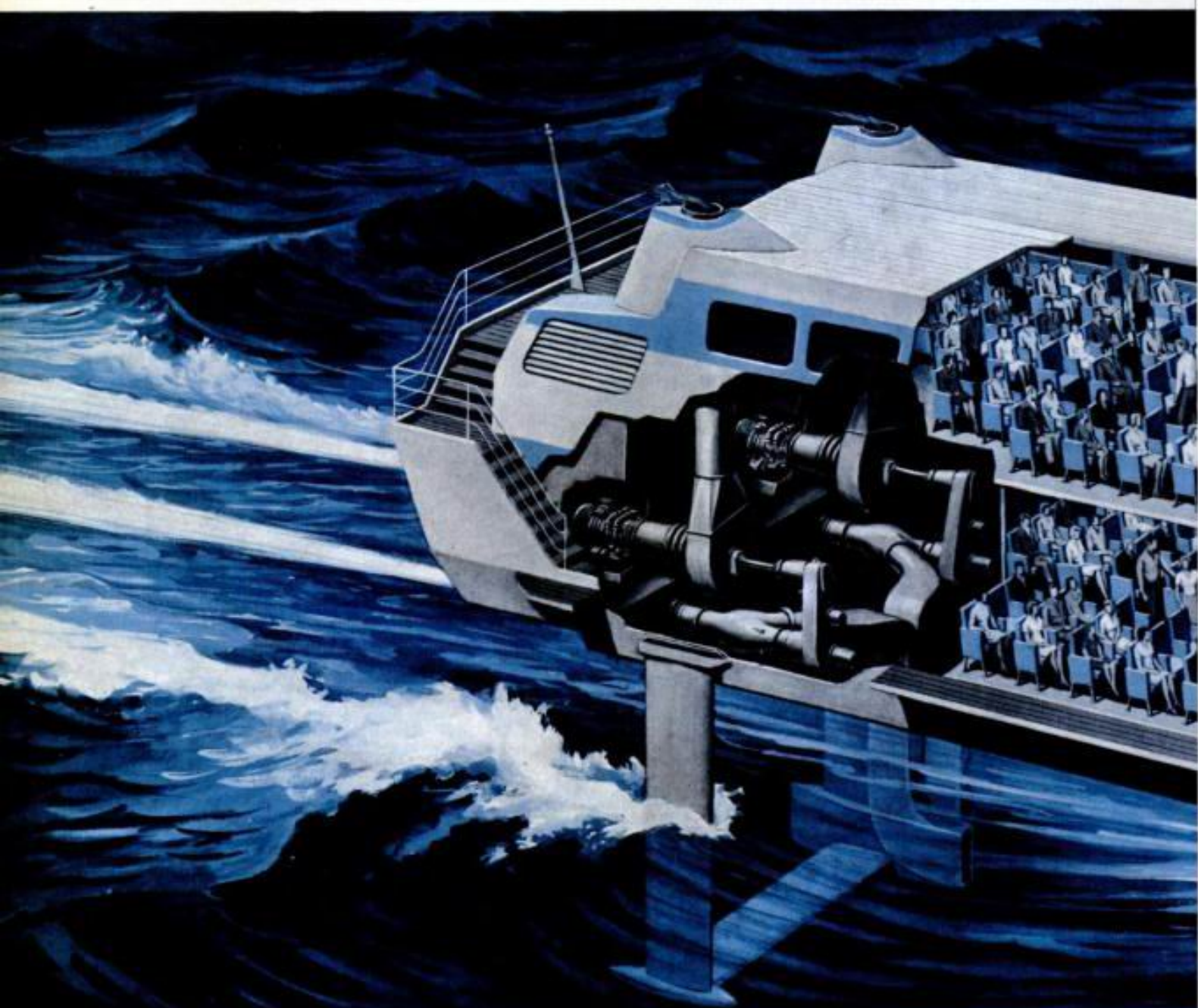
Jumbo Jetfoil Will

Boeing's new craft will cruise at 50 mph—fastest commercial hydrofoil. And a special submerged foil system will give a comfortable ride even in 12-foot waves

By BEN KOCIVAR / *PS Consulting Editor, Flying*
DRAWINGS BY RAY PIOCH

Nearly a decade ago, thousands of people "flew" on a fleet of small 24-passenger hydrofoils that operated regular 30-mph service between Manhattan and the New York World's Fair. Ever wonder what happened to them? A few are still in service in various parts of the U.S., but their use is sparse.

Now there's big news again. One of the world's biggest airplane makers, Boeing, has announced it is going into the boat-building business. The aerospace giant



AIR-CUSHION



SURFACE-PIERCING



SHALLOW-DRAFT



SUBMERGED

How air-cushion concept differs from hydrofoils

Air-cushion vehicle actually floats above land or water on air pumped down from above, dribbling out the sides. Sur-

face-piercing and shallow-draft foils are for smooth water. Deep, submerged foils in rough seas need automatic controls.

Be Super-Fast, Super-Smooth

will produce a fleet of 250-passenger, turbine-powered hydrofoils able to cruise in ocean waters at a zippy 50 mph. Boeing already has orders for 11 craft (at \$3.5 million each) for use in the Hawaiian Islands, Hong Kong, and across the English Channel. Not yet announced by Boeing, but strongly rumored, is domestic service for New York, San Francisco, and other major cities. Boeing forecasts a total market for about 40 of its boats within five years, and 100 within 10 years.

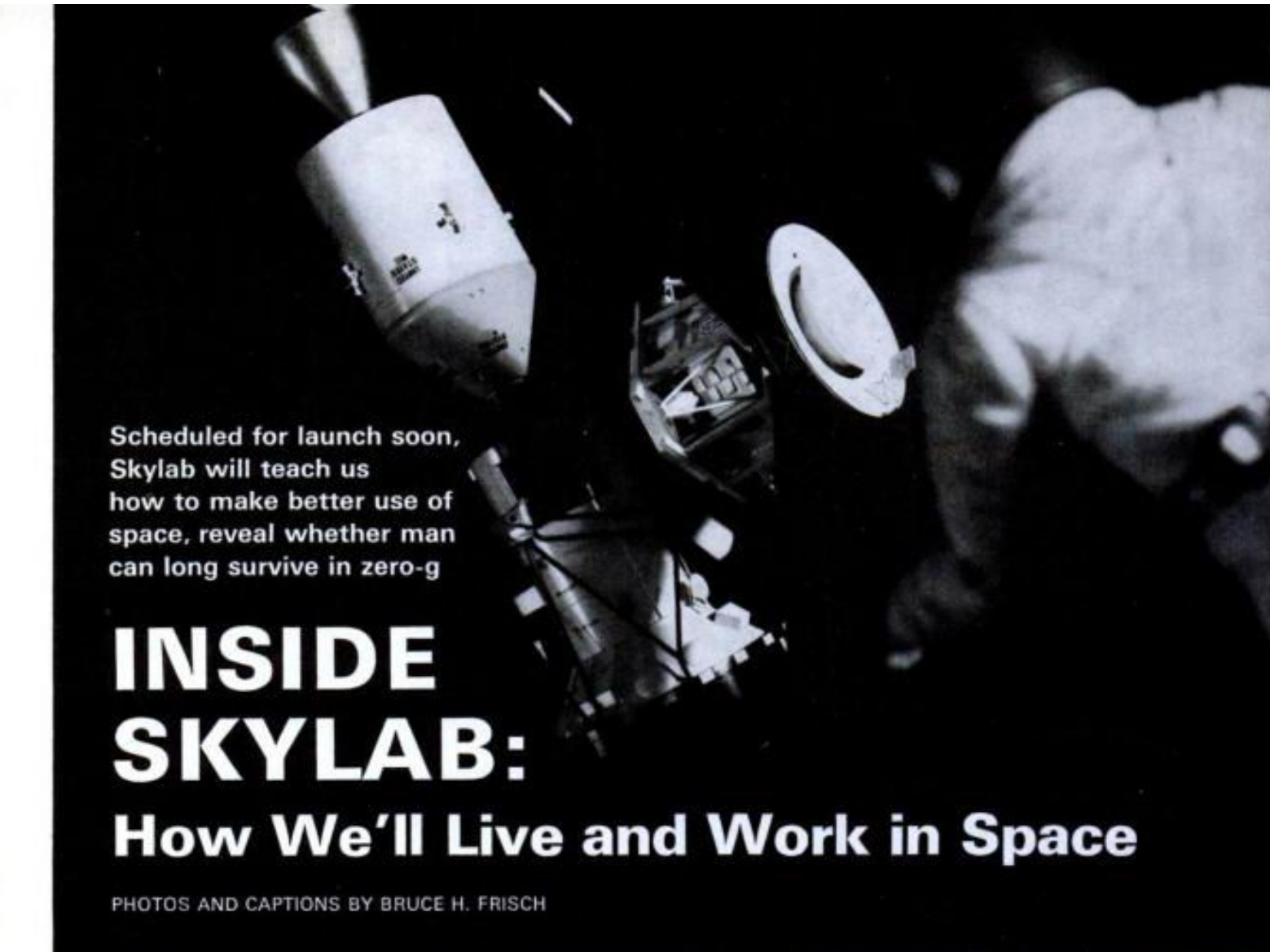
First delivery is scheduled for June '74, but a non-passenger test ship will be launched in November. Having ridden Italian, American, Swiss, and Russian hydrofoils, I can't wait to climb aboard this brand-new Yankee design.

A commuter hydrofoil? It could work out. The Russians have over a thousand of their own in various sizes from small runabouts to giant transports. There

Continued



Artist's conception of Boeing's new super wide-bodied Jetfoil shows double-decker seating arrangement. Forward and aft flaps operate differentially and provide precise pitch variation and height control over the water's surface. The aft flaps operate like an airplane's ailerons; they provide roll control for directional changes. Jetfoil banks all its turns just like an airplane. The forward strut is steerable and the fully automatic control system provides the proper amount of bank to coordinate the rate of turn. Jetfoil's displacement is 100 tons; length, 91 feet; beam 31 feet; draft with foils up, five feet; foils down, 16 feet. The commuter version will carry 250; tourist type with baggage, 190. First model will be ready in Nov. '73.



Scheduled for launch soon, Skylab will teach us how to make better use of space, reveal whether man can long survive in zero-g

INSIDE SKYLAB:

How We'll Live and Work in Space

PHOTOS AND CAPTIONS BY BRUCE H. FRISCH

Teams of three astronauts will fly to Skylab in Apollo command modules. Model above simulates orbiting lab.



Rings lock together to make watertight shower stall. Crewman will wet himself with a spray gun, dry with a sponge on a vacuum-cleaner-like head.



Body's work efficiency in space will be tested as astronauts regularly pedal an instrumented exercise bicycle. Oxygen consumption is recorded for later study.



Converted Saturn IVB rocket makes up the enormous workshop, gives Skylab the largest volume ever put into orbit. Fisheye-lens view is from upper level.



For standup eating required at wardroom table, stirrups will anchor astronauts. One removable tray is in place. Reduced-pressure tank (background) will test blood circulation.



Control console for Skylab's solar telescope includes TV screens to assist operators aiming it. The telescope can view solar radiation such as X rays blocked by Earth's atmosphere.



Experimental maneuvering units for work in space will be flown inside the upper level. Inset shows manual controls. A gyro can automatically stabilize it, leaving hands free.



Motor-driven chair will spin astronauts to test sensitivity of inner-ear mechanisms to motion, and perception of body's orientation during zero-g living.



Sleeping-bag restraint can be vertical to conserve space—there is no up or down in weightless environment. Optional netting steadies sleeper's head.



Neatness counts when trash does not fall conveniently to the floor. Bags passed through this airlock will enter the rocket's empty oxygen tank below.

World's Tallest in Toronto—

Needle-shaped 1805-foot TV tower will be record-high freestanding structure

By HERBERT SHULDINER ILLUSTRATIONS BY RAY PIOCH

Inching skyward at the rate of 18 feet a day, a new cloud scraper is reaching for the title of world's tallest freestanding structure.

Begun last month, the new CN Tower in Toronto, Canada, will eventually be 1805 feet tall—towering above the Sears Building in Chicago, the Moscow TV tower, and all other man-made skyscrapers. Of course, there's still the TV transmission tower of KTHI in Fargo, N.D., which is 2063 feet tall—but it's held up by guy cables and is not self-supporting.

The CN Tower, which is being bank-

rolled by Canadian National Railways, is seemingly pulling itself up by its bootstraps. It's being built with the aid of a rig that has 54 jacks on top. This raises a series of slip forms to allow continuous pouring of concrete. By the time four feet of concrete is poured, the bottom few inches have cured enough to support weight. So the slip forms are raised by that much. The pouring goes on around the clock, five days a week.

Project engineers expect the great concrete shaft will be completed by November. The concrete will top out

at 1500 feet. Then a 305-foot television-transmission antenna mast will be added to give the structure its full height.

Walls of the CN tower range from thirty inches to eighteen inches in thickness at the central core. The wings are eighteen inches thick. The building is made of reinforced and pre-stressed concrete. Reinforcing rods are of varying thicknesses. About 53,000 cubic yards, or 106,000 tons of concrete will be used in the structure. There will also be 5000 tons of reinforcing [Continued on page 124]

Lofly "Sky Pod" houses observation and restaurant levels, which wrap around Toronto tower beginning at 1100-foot level. Tables in the restaurant will be on a revolving platform, giving diners a 360-degree view of the city below them. Getting up to the Sky Pod will be a breathless experience. Elevators in glass-encased shafts will speed you from street level to the six-story pod in a minute. The elevators will be able to carry 1300 people an hour each way. Tower officials say that visibility will be 75 miles on clear days. In addition to the restaurant, indoor and outdoor observation decks, there will be broadcasting studios, a snack-bar, and display areas in the pod. A total of 70,000 feet of space is available in the six levels of the 80-foot-high pod, which ranges between 100 and 140 feet in diameter. Above the Sky Pod will be a 305-foot transmission antenna that will improve broadcast reception in the area.

TRANSMISSION ANTENNA



MICROWAVE ANTENNAS

EXTERIOR OBSERVATION DECK

INDOOR OBSERVATION DECK

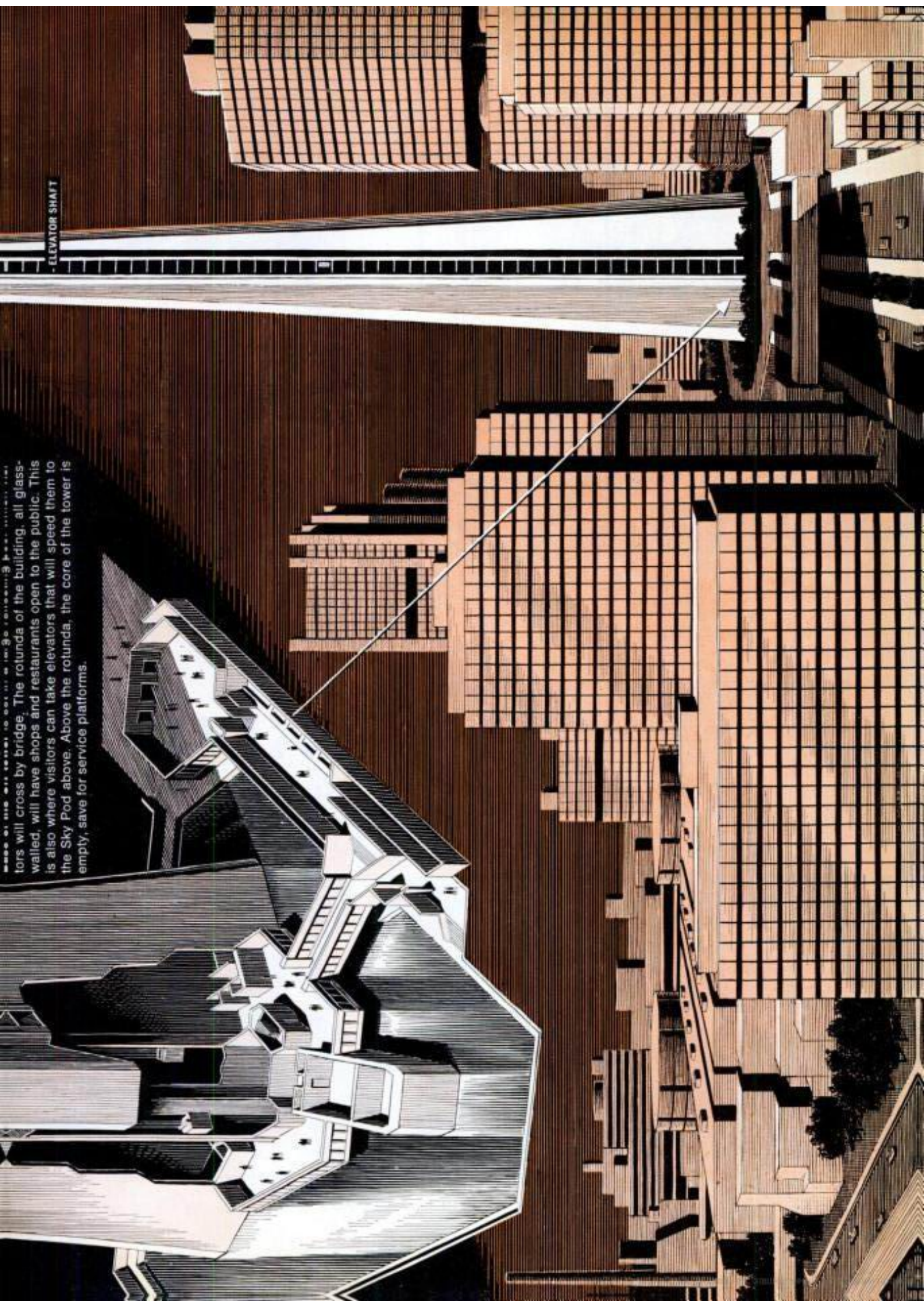
RESTAURANT

SKY POD

UHF-TRANSMISSION STUDIOS

FM-TRANSMISSION STUDIOS

WALLS OF THIS SKY POD WILL BE GLASS, ALLOWING VISITORS TO SEE THE CITY AND BE SEEN. THE ROTUNDA OF THE BUILDING, ALL GLASS-WALLED, WILL HAVE SHOPS AND RESTAURANTS OPEN TO THE PUBLIC. THIS IS ALSO WHERE VISITORS CAN TAKE ELEVATORS THAT WILL SPEED THEM TO THE SKY POD ABOVE. ABOVE THE ROTUNDA, THE CORE OF THE TOWER IS EMPTY, SAVE FOR SERVICE PLATFORMS.



ELEVATOR SHAFT



Spacemen Get Long Reach with Remote-Control Aids

By
WERNHER von BRAUN
PS Consulting Editor, Space

Sophisticated puppets called "teleoperators" can relieve our astronauts of many difficult or dangerous tasks performed in orbit



When one of our coming Space Shuttles repairs a satellite in orbit, or retrieves it for return to Earth, it's likely the job will be done by remote control. Sometimes the actual operator may not even be one of the Shuttle crew, but a man down on the ground.

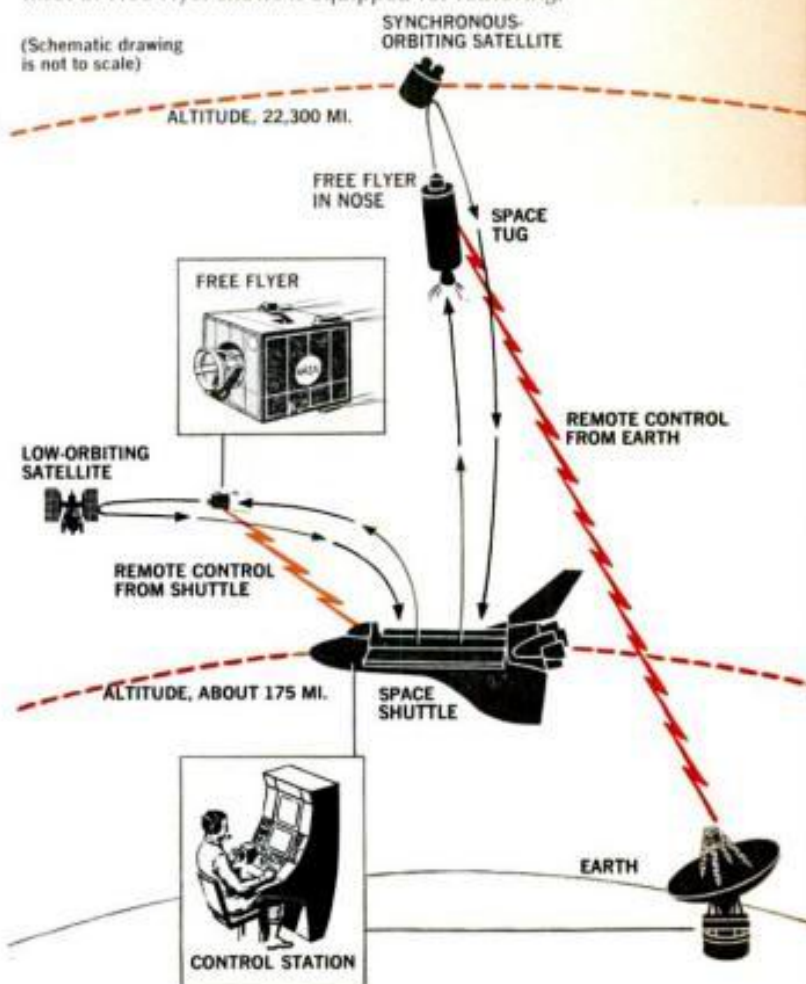
Little-realized by the public is how extensively the manned Shuttle will rely on *unmanned* devices and ve-

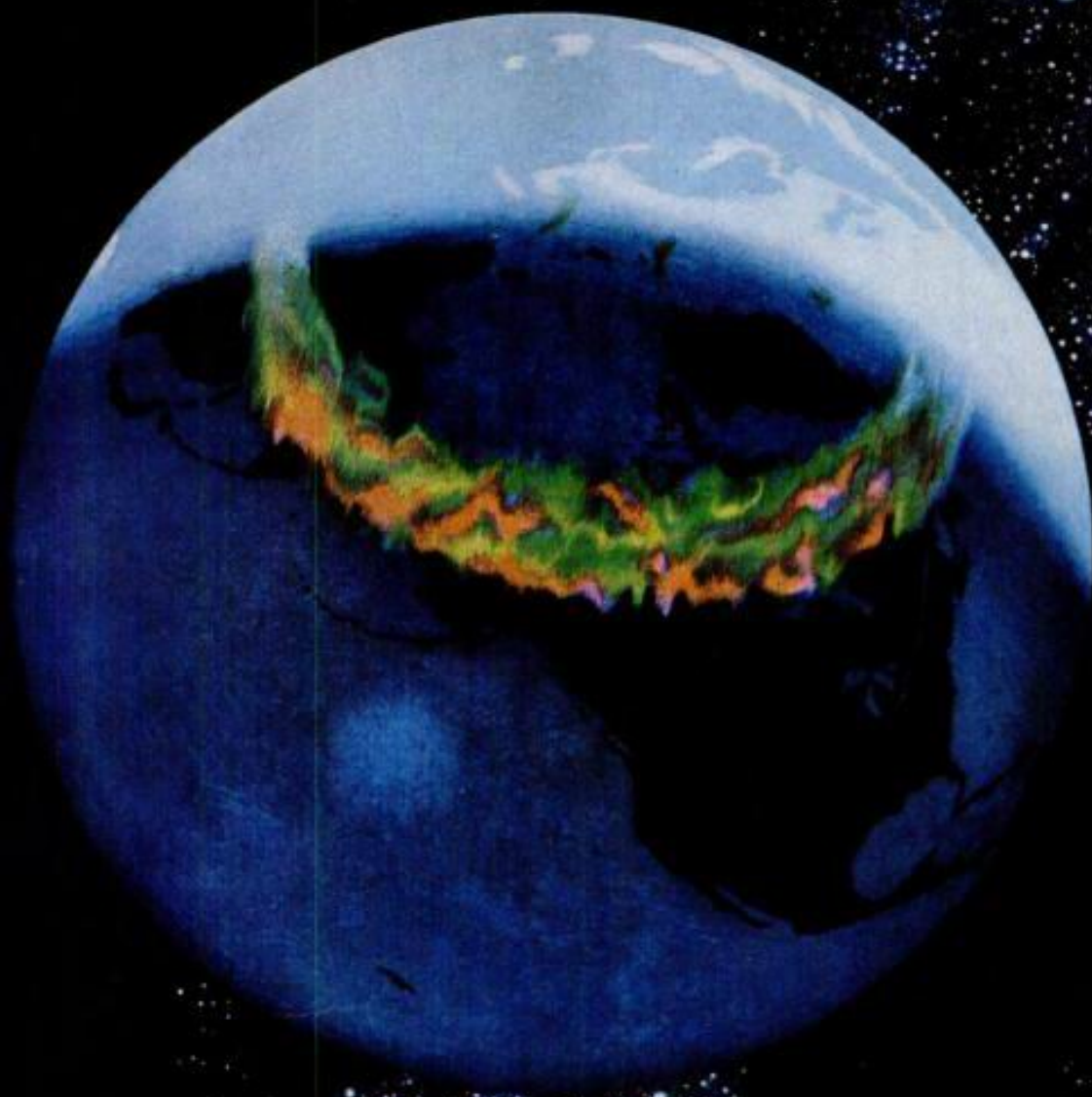
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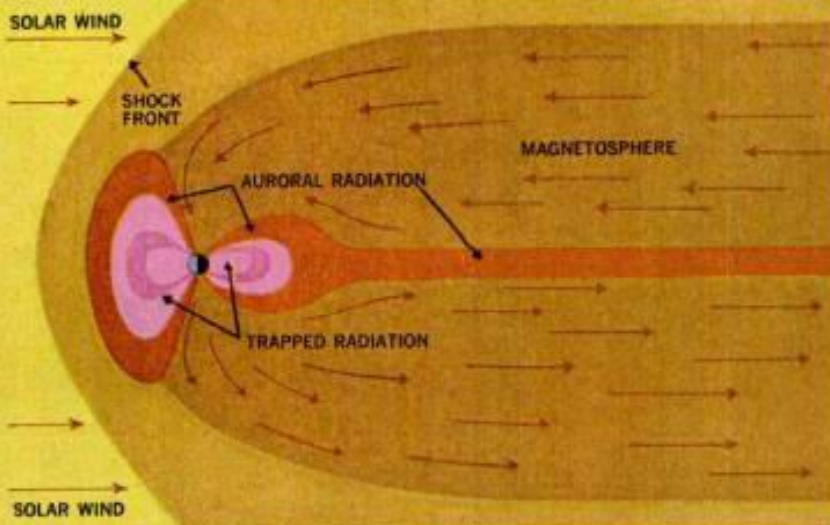
Mechanical arms up to 50 feet long, remotely operated from within, look like "feelers" on nose of Space Shuttle. North American Rockwell artist shows craft launching Space Tug (upper left), pulling satellite it will boost into higher orbit than Shuttle can reach. Schematic drawing below illustrates how orbiting Shuttle will use a radio-controlled Free Flyer, a mini-spacecraft with interchangeable towing gear or manipulators, to retrieve or repair a satellite. Inset of Free Flyer shows it equipped for retrieving.

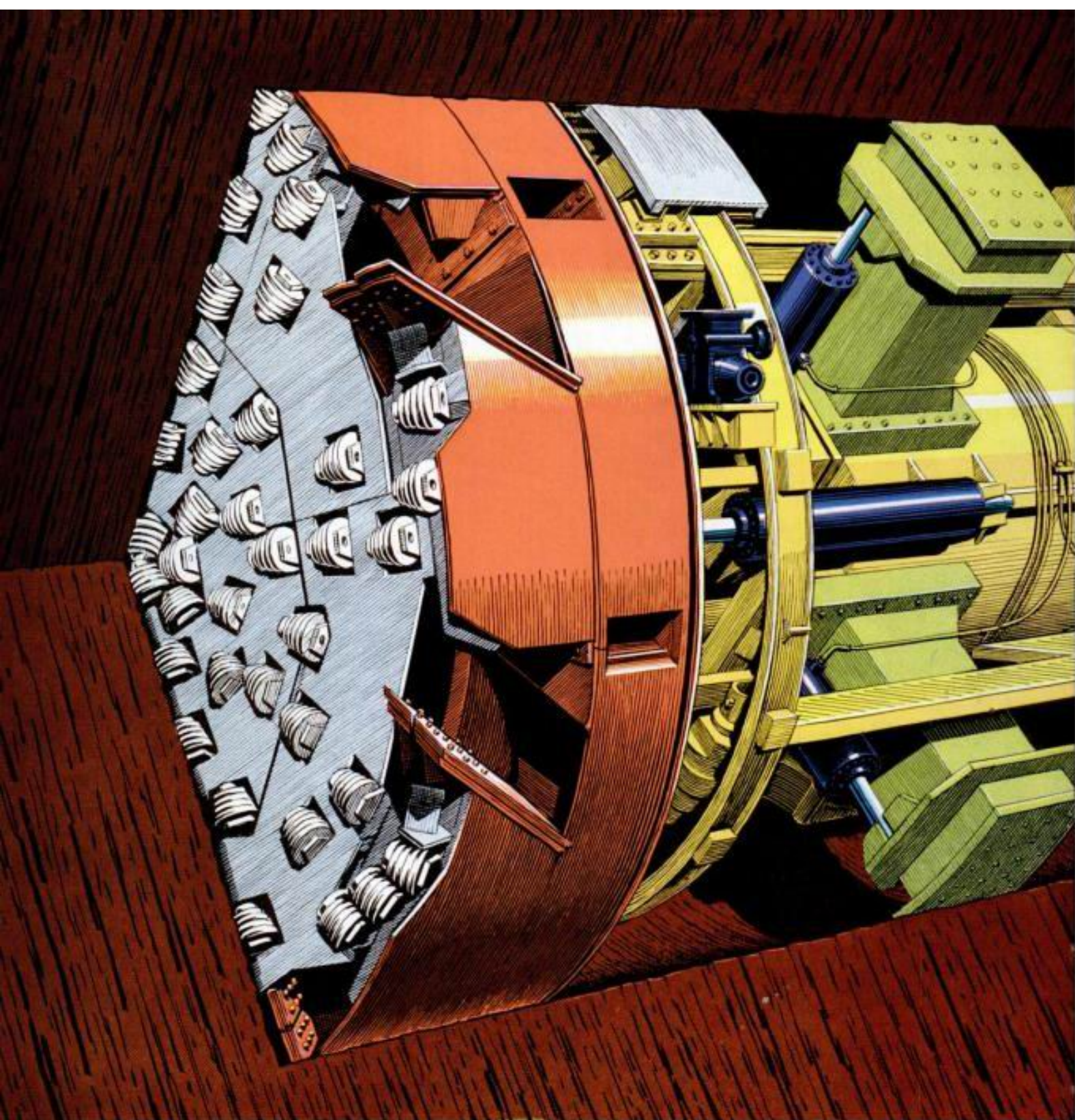
(Schematic drawing is not to scale)





Auroral oval—zone of northern lights' maximum activity—is seen here as huge band lop-sidedly ringing Earth's geomagnetic pole. Intense solar storms can shift oval closer to equator. The lights, visible only at night, glow when electrically charged particles shot from the sun (solar wind) collide with gas molecules in our atmosphere. Scientists think that these particles are first trapped in the magnetosphere (right), region of concentrated magnetic field, then whipped back toward Earth at speeds higher than particles in the solar wind itself.





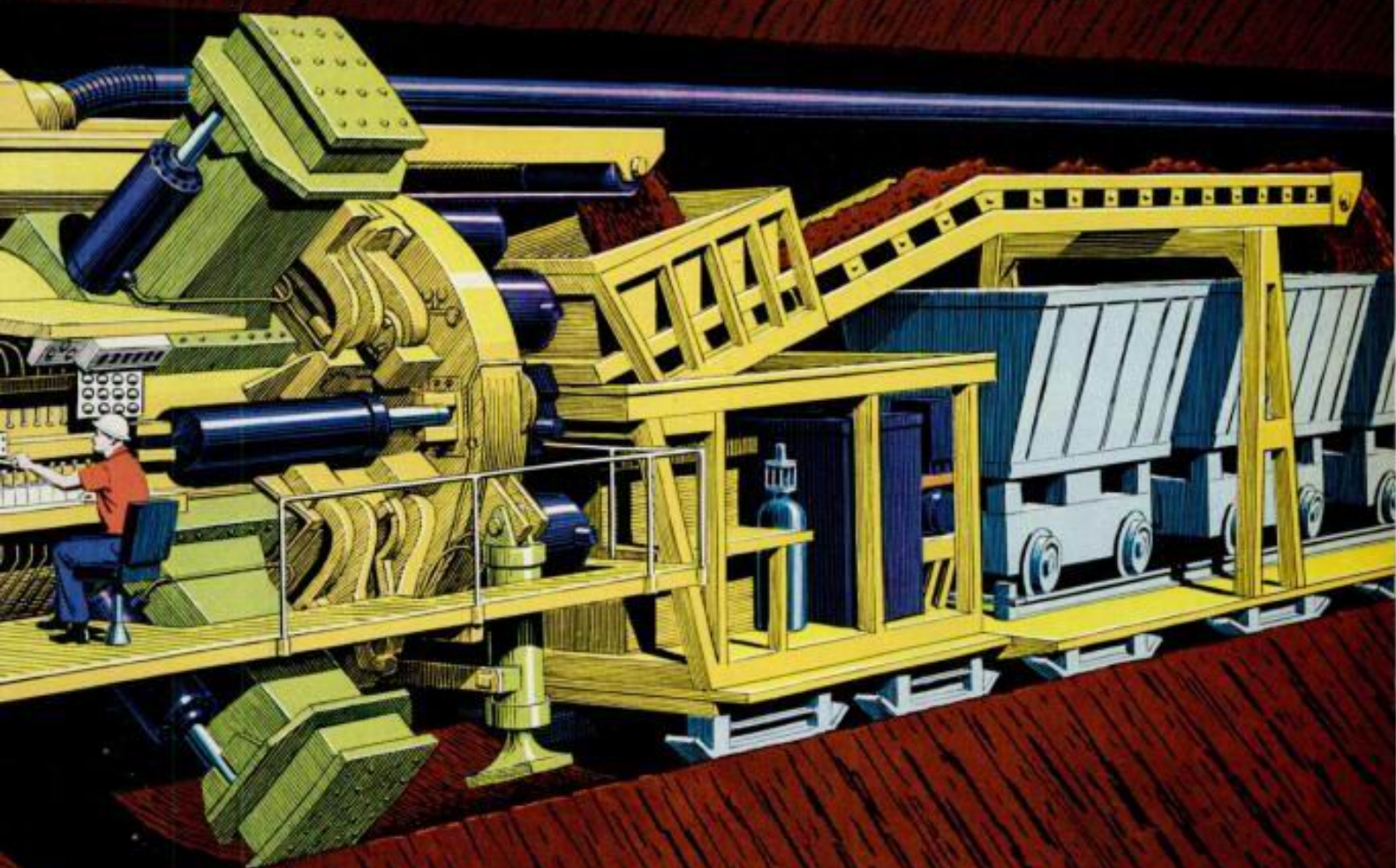
Deep in the Earth with the

Maybe right now, underneath you, one of those million-dollar machines is chomping through rock—as fast as 400 feet a day

By **ROBERT GANNON**
DRAWINGS BY RAY PIOCH

Seventy feet under the surface of suburban Rochester, N. Y.—unknown to most of the residents living above—a massive mole is eating its way through the earth. It's been down there since spring of last year, and right now should be under or beyond Thomas' Creek. It's chewing its way through 5½ miles of hard siltstone and shale, leaving an 18-foot sewage tunnel in its wake.

Until just the last few years, the tunnel could be dug only by the conventional drill-and-blast method: You bored holes in the tunnel face, shoved in dynamite



Monster Moles

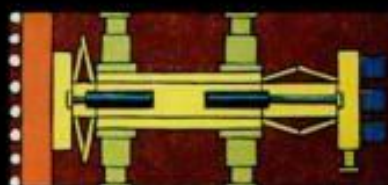
sticks, exploded them, and hauled off the rubble. After a full day's work, you'd progressed maybe 50 feet, and had listened to any number of complaints from residents about the blasting.

But now the rock-boring *mole* has come along, and tunnelers are finding it can munch its way through up to 100 feet of hard rock a day, and through more than twice as much softer rock (the record is 403 feet). You can tunnel without surface-blast vibration or fumes. It's safer, too, and it gives a nice smooth hole as well.

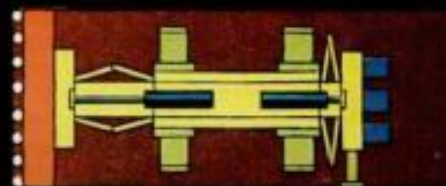
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How the machine "jacks" itself forward

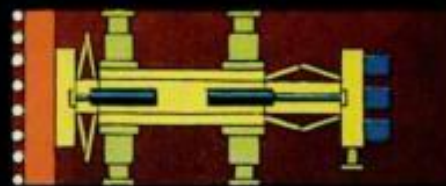
1. Start of boring cycle. The machine (yellow) is clamped by the clamping legs (green). Boring head (red) is ready to move forward.



2. Boring cycle ends. The head has moved forward, completing cut. Clamping legs are retracted; rear support legs are extended.

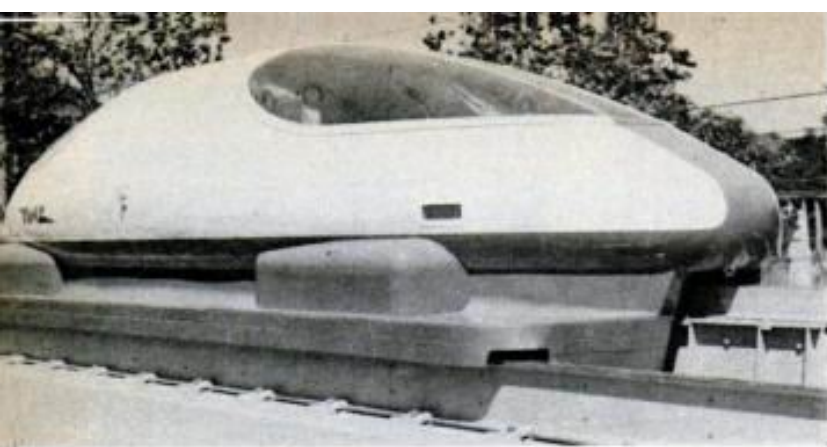


3. The clamping legs have moved forward and are now clamped against the tunnel. Rear support legs are retracted.



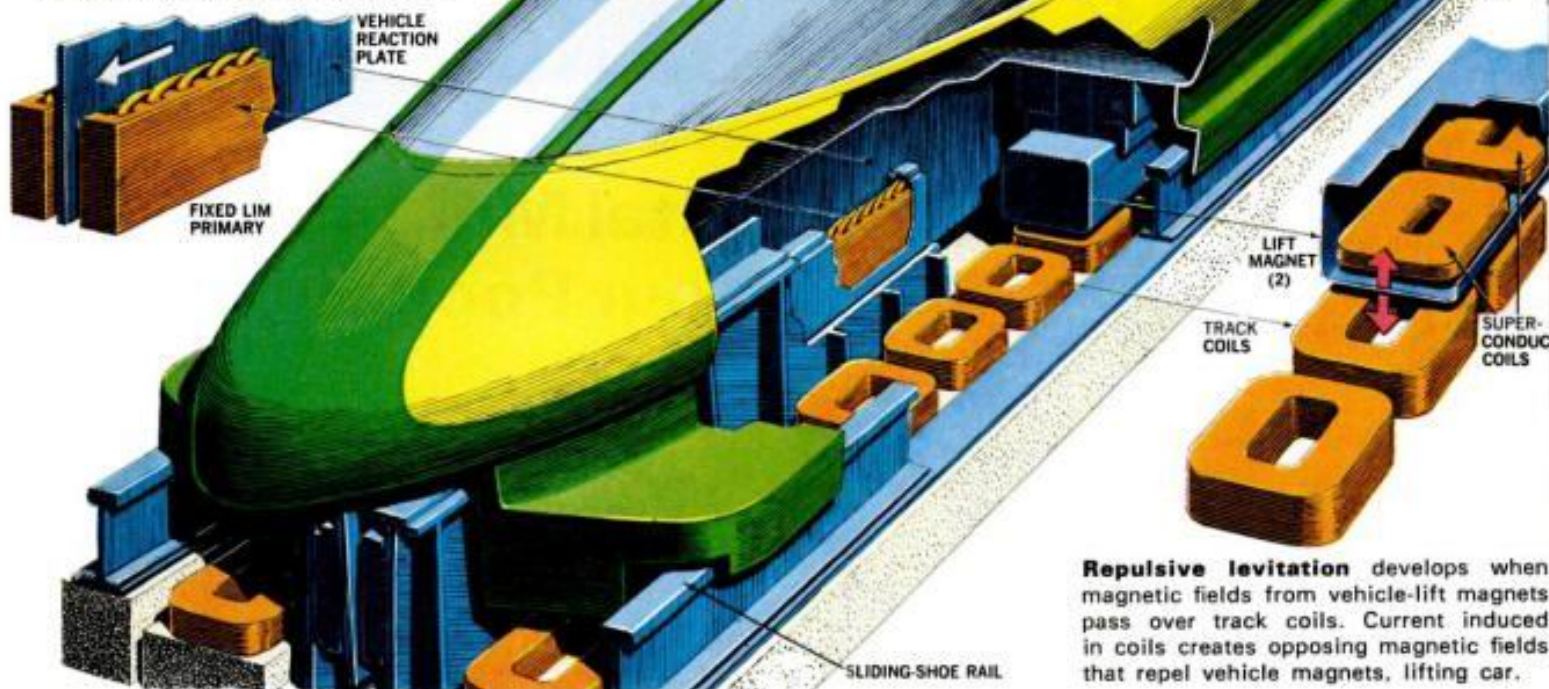
4. End of the reset cycle. Boring head has moved forward again, making next cut in tunnel face.





Research vehicle built for Japan National Railways has two superconducting magnets for repulsive levitation. Two strings of passive track coils anchored in the 1580-foot guideway produce a magnetic levitation (maglev) force as the vehicle moves over them. Linear induction motors (LIMs) propel the vehicle. At slow speeds, sliding shoes support the car until a maglev force develops. The 3.5-ton vehicle, suspended four inches, has traveled up to 40 mph.

Linear induction motor (LIM) has fixed primaries spaced along the guideway. A reaction plate suspended from the vehicle is LIM secondary. As the reaction plate passes between primary coils, currents induced in the plate oppose the electromagnetic field of the primary. This opposition thrusts the vehicle forward.



Repulsive levitation develops when magnetic fields from vehicle-lift magnets pass over track coils. Current induced in coils creates opposing magnetic fields that repel vehicle magnets, lifting car.

MAGLEV: How They're

Super trains that can "fly" at 300 mph on magnetic cushions are coming. Here's a look at vehicles built to test propulsion motors and levitation hardware

By **DAVID SCOTT** / *PS* European Editor and **JOHN FREE**
ILLUSTRATIONS BY RAY PIOCH

A major revolution in high-speed ground transportation (HSGT) will get off the ground in Germany, Japan, and Canada during the next two years. Significant, but smaller-scale developments, will occur in the U.S. Wheelless trains that "fly" above special rails and guideways using magnetic levitation (maglev) are rapidly approaching commercial

reality. Considered a way-out idea for ground transportation just seven years ago, maglev planning should see these developments by the end of 1975:

- In West Germany, three companies, with extensive government financial support, will begin testing full-scale maglev vehicles on a 46-mile proving track shaped like a

dog biscuit near Augsburg. Government funding will then be stepped up to put maglev trains on public rails as quickly as possible.

- In Japan, the Japanese National Railways should have decided which of two vehicle-propulsion systems being tested should be suitable for a 280-mile maglev link between Tokyo and Osaka. Construction may be underway on a system that by 1985 will be whisking train passengers between the two cities in about an hour.

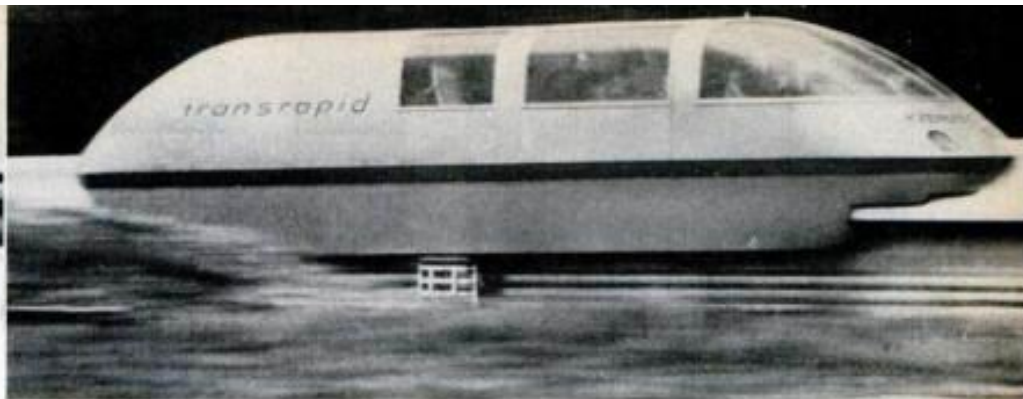
- In Canada, a 2.5-mile maglev test track should be completed in Toronto. Krauss-Maffei, one of the three German firms, has contracted to build the maglev system. Ontario's government has said no to a

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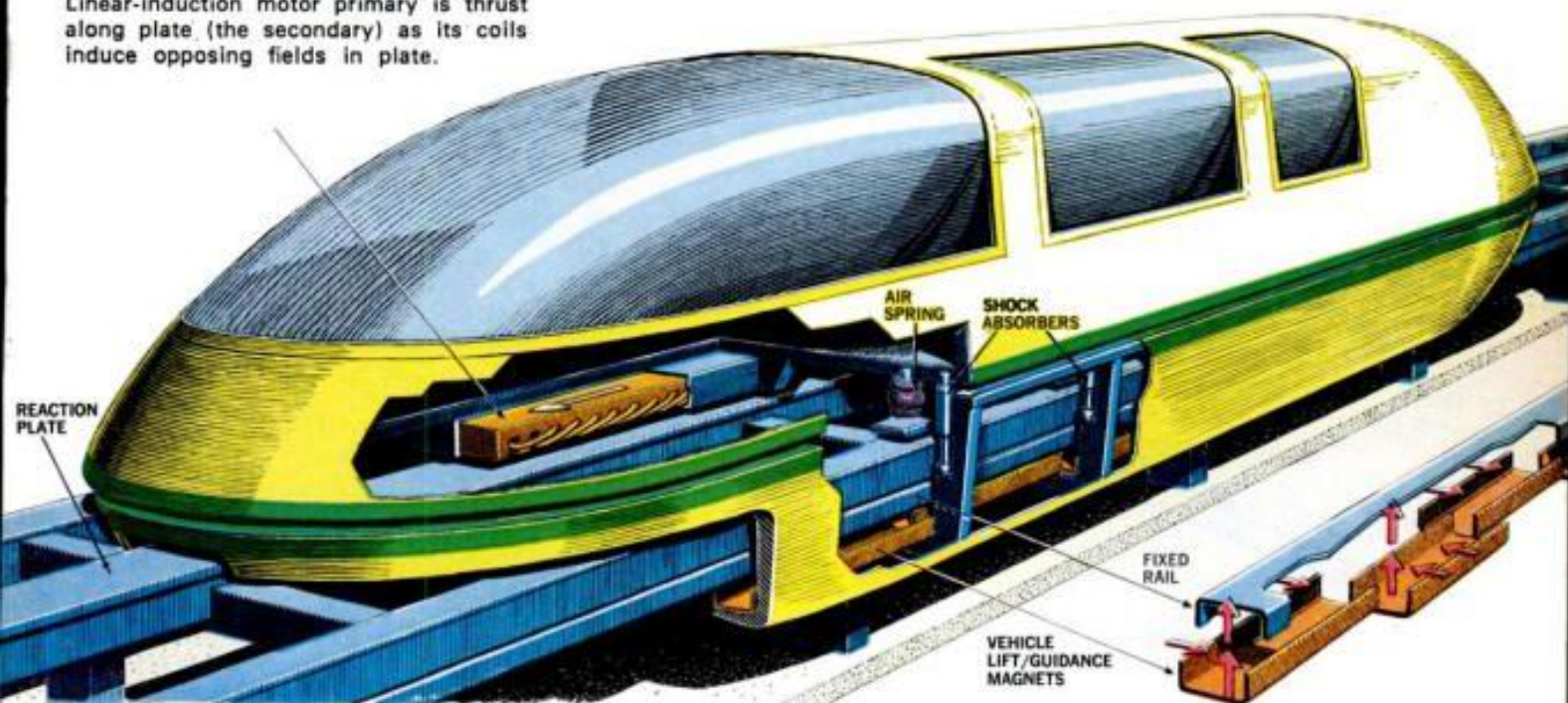
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Zippering along German test track, right, is Krauss-Maffei's 11-ton test car, built in 1971. Above is a KM concept model of a future maglev vehicle.



Flat, single-sided LIM in car works against a metal reaction plate on track. Linear-induction motor primary is thrust along plate (the secondary) as its coils induce opposing fields in plate.

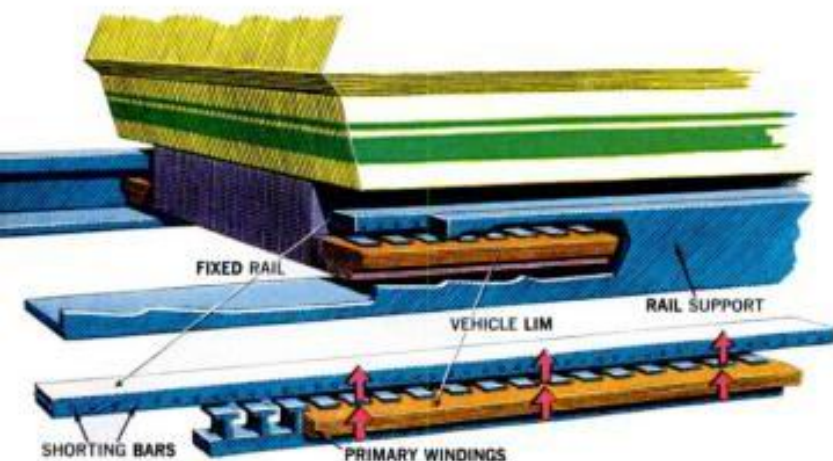


Second-generation KM research vehicle nearing completion is a modification of original car (photo above). Double-sided vertical LIM is being replaced by more powerful single-sided LIM placed horizontally under the floor. This flat

LIM eliminates the massive reaction-rail tunnel needed in original vehicle. To lift the car, unique U-channel electromagnets are attracted to the steel rails (detail, right). Sensors determine distance to rail to hold half-inch air gap. Adjoining

magnets are laterally offset, each pulling sideways in opposite directions to provide guidance. This self-centering action keeps the vehicle aligned on the track without the additional complexity of separate guidance magnets.

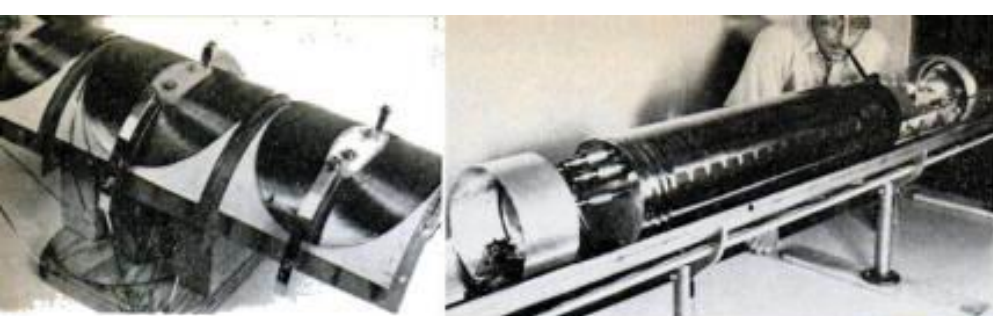
Getting Trains Off the Ground



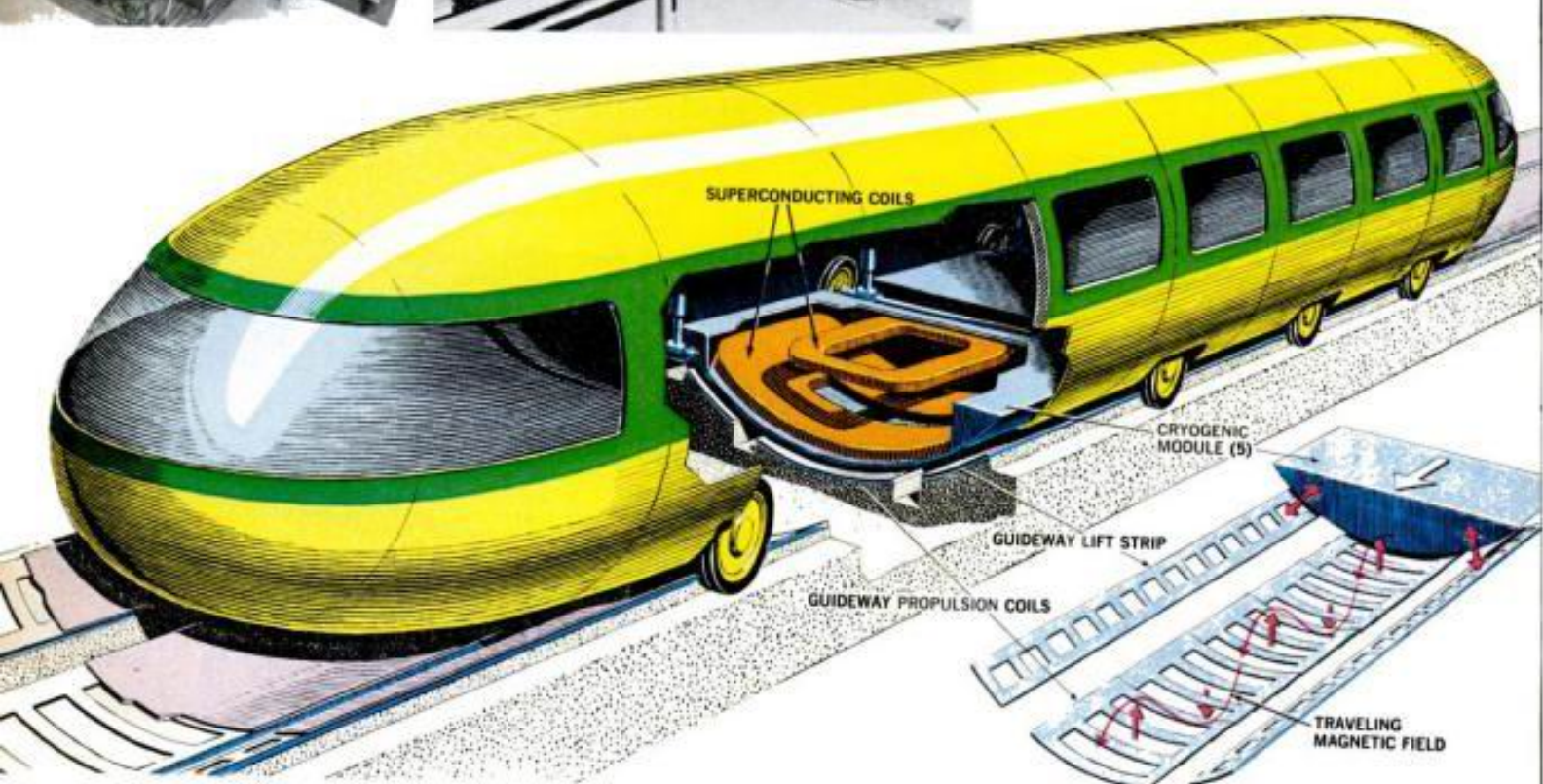
Single-sided linear induction motors on both sides of Romag induce fields in metal rails that both lift and propel vehicle. Sensors regulate voltages to maintain a fixed rail/motor gap. By changing frequency of three-phase power applied, vehicle moves horizontally. Rail shorting bars act like a motor rotor, providing thrust.

Romag test vehicle developed by Rohr Corp. in California first ran in 1971. A 12-passenger "people mover" like the one below was demonstrated on a 60-foot track at Transpo '72. Romag has unique LIMs that both suspend the vehicle (attractive levitation) and propel it. The concept can be applied to larger vehicles, says Rohr.



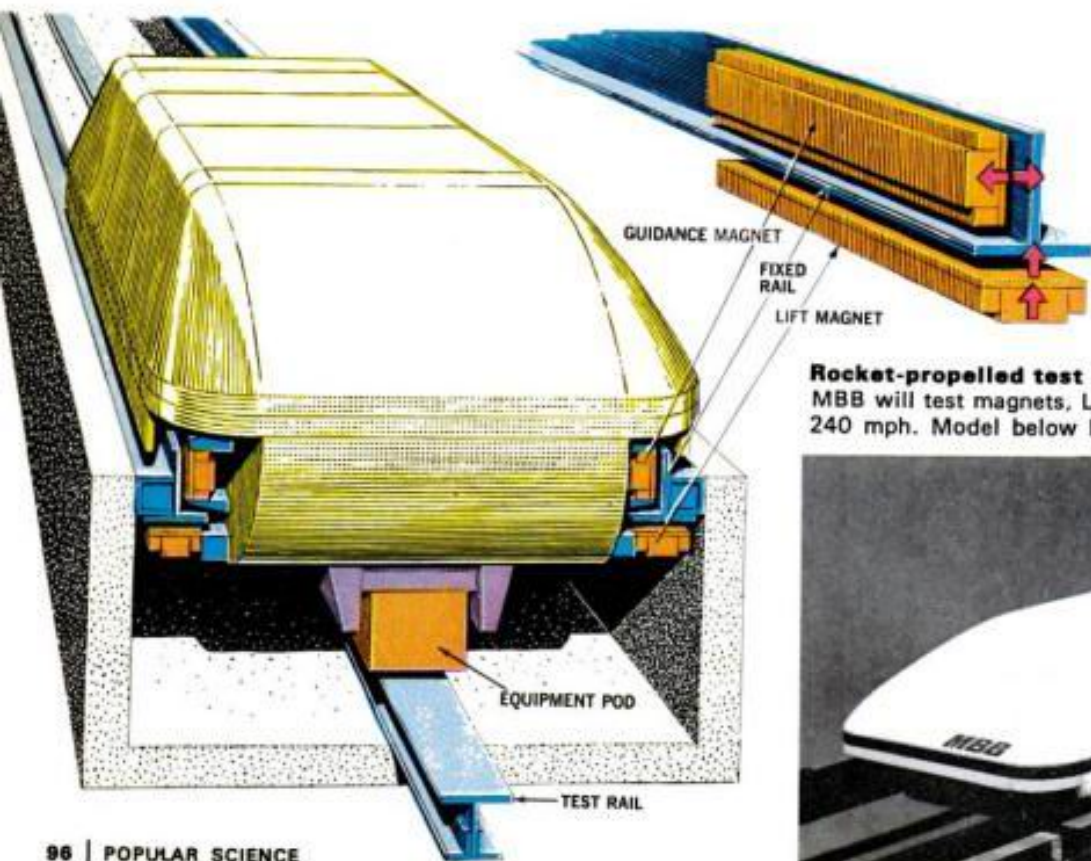


Scale model of M.I.T. Magneplane (left) is supported by saddle-shaped superconducting coils (far left) beneath model. Coils, readied here for an epoxy coating, lose their resistance in liquid helium, carry 200 amps.



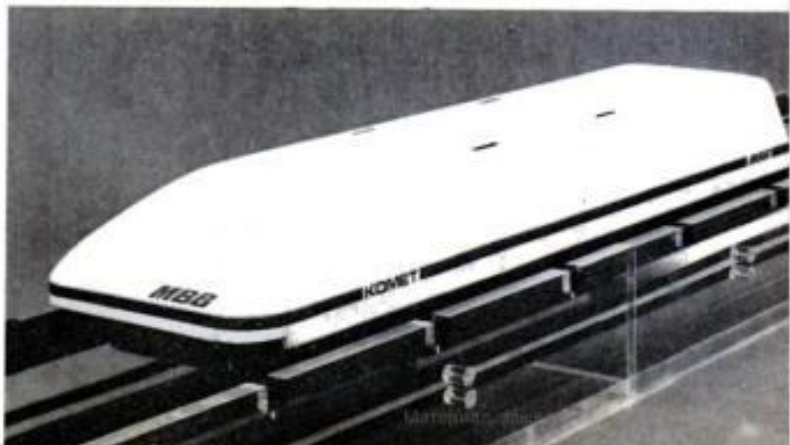
Passenger-sized Magneplane—not under construction—would contain five modules for superconducting coils. Larger bottom coils induce a repulsive levitation force in guideway lift strips. Smaller coils near the floor shield passengers from strong fields. Linear synchronous motor (LSM) would propel vehicle: Three-phase AC is fed to overlapping propulsion

coils as vehicle approaches. Detail shows the magnetic field from one phase of AC. Voltage is controlled so travelling fields interact with the powerful fields in the modules, pulling Magneplane along on a magnetic "surf." Wheels would retract as vehicle built up enough speed for levitation to develop, enabling it to bank in the guideway.



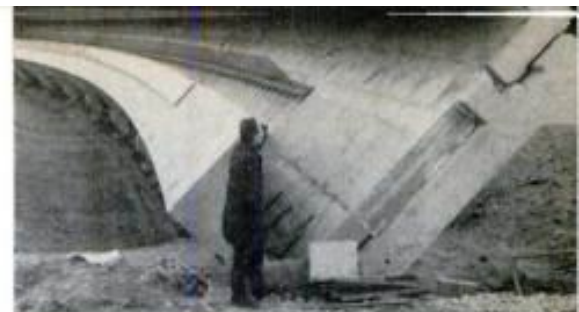
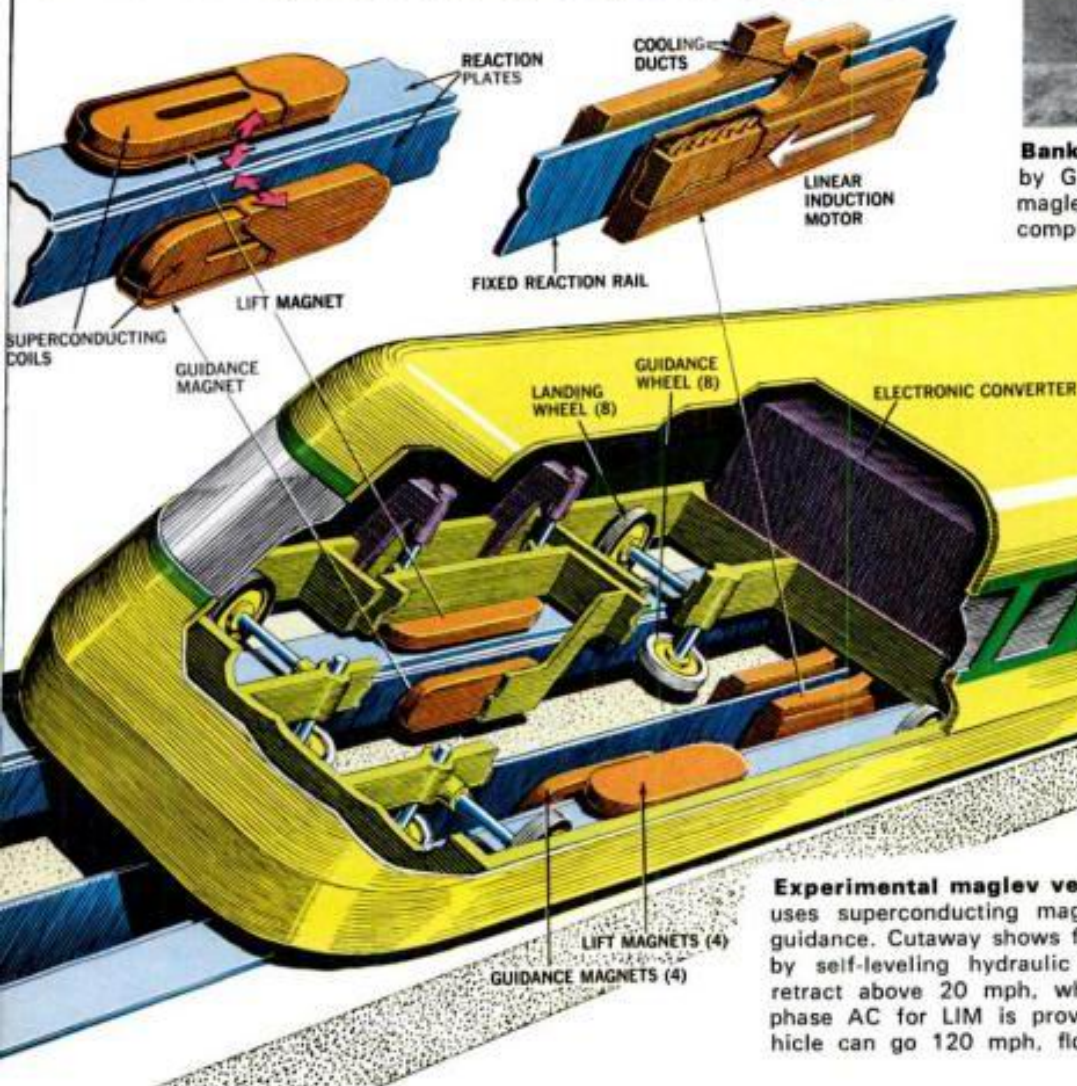
Attractive levitation suspends test car as on-board electromagnets are drawn to fixed rail. Guidance magnets work against vertical section of rails to keep car centered in test track. Inductive sensors next to each magnet determine the distance between magnets and rails. A liquid-fuel rocket accelerates unmanned test car, while equipment is evaluated against the flat rail.

Rocket-propelled test car under construction by Germany's MBB will test magnets, LIMs, guidance and control systems at 240 mph. Model below has streamlined design.



Superconducting magnets for levitation and guidance are repelled from continuous plates. Eddy currents induced in plates create opposing magnetic fields. Magnets must be moving above 20 mph.

Vehicle-mounted linear induction motor has double-sided primary straddling a fixed reaction rail. Interaction of the primary's field with currents induced in the rail thrusts the vehicle forward.



Banked 45-degree circular track built by Germany's Siemens will test 15-ton maglev vehicle below. The test track, now completed, is 300 yards across.

Experimental maglev vehicle being completed by Siemens uses superconducting magnets for repulsive levitation and guidance. Cutaway shows forward subframe, linked to vehicle by self-leveling hydraulic struts. Landing/guidance wheels retract above 20 mph, when magnets are effective. Three-phase AC for LIM is provided by solid-state converter. Vehicle can go 120 mph, floating 4 to 8 inches above track.

major highway program in favor of a \$1.3-billion modern transit program. Roughly half of these funds will be used to build a revenue-producing maglev line.

Maglev is one of the most promising of many new transportation vehicles being developed [PS, May '72]. Magnetically levitated vehicles are silent, nonpolluting, have no moving parts, and consume less energy than other high-speed systems.

Maglev variations. But as with other transportation systems, maglev vehicles will serve a variety of functions. JNR's high-speed maglev train, for example, will carry passengers between Tokyo and Osaka at nearly 300 mph. Slower 150-mph maglev trains under development elsewhere will carry passengers between suburbs, cities, and airports. Still slower-moving maglev vehicles will be used for personal rapid transit (PRT). These "people-mover" vehicles [PS, Nov. '71] will operate within cities or airport terminals to speed transportation.

One wheelless competitor to maglev is the tracked air-cushion ve-

hicle (TACV). These vehicles ride on a noisy cushion of air generated by on-board compressors. Although France remains committed to operating a TACV line, Britain early this year abandoned development of their Hovertrain after spending \$12 million.

In the U.S., the Federal Railroad Administration has committed some \$30 million to TACV research since 1967. As a result, Grumman Corp. has built a jet-propelled test TACV, and Rohr Corp. has a contract for a 60-passenger TACV. But the FRA's stress on TACV has resulted in a U. S. maglev program that's "rather sad" in comparison with other countries, as one maglev proponent puts it. Barely \$1 million has been funded for maglev research programs by the government.

Stanford Research Institute, one recipient of funds, has tested a magnetically levitated sled [Science Newsfront, PS, March '73]. Ford received a study contract. Although Rohr Corp. has built privately funded maglev vehicles (see drawing), and is developing a second-genera-

tion version, government support is a must to develop 300-mph city-to-city maglev lines.

Why invest billions in HSGT? Anyone traveling in the technologically advanced nations quickly discovers the reasons. Highways choked with cars moving at a crawl are becoming unbearable in many cities. Toronto residents actually halted construction of a highway cutting an ugly swath through their city, opting for a major urban transit program.

Airports and overcrowded air corridors are approaching a crisis state, too, as travelers become more affluent and develop a preference for jets. Yet airport-expansion plans now encounter stiff public opposition because of jet noise, pollution, and land use. Transportation experts point out that the 7.5 square miles of New York's Kennedy Airport would accommodate a 95-foot-wide guideway from Boston to Washington, D. C.

Maglev beats flying. Significantly, for distances up to 300 miles, HSGT can provide station-to-station

[Continued on page 133]